APPENDIX D

ECOLOGICAL MODELING FOR JACKSONVILLE HARBOR DEEPENING GRR II

JACKSONVILLE HARBOR NAVIGATION (DEEPENING) STUDY

DUVAL COUNTY, FLORIDA

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Ecological Modeling for Jacksonville Harbor Deepening GRR II

Draft Report

Prepared for

U.S. Army Corps of Engineers, Jacksonville District
Jacksonville, Florida

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1.0 INTRODUCTION

1.1 Purpose

The U.S. Army Corps of Engineers (USACE), Jacksonville District is preparing a General Revaluation Report (GRR) to evaluate proposed deepening of the Jacksonville Harbor navigation project. The Jacksonville Harbor Deepening GRR-2 will evaluate engineering, economic, and environmental factors related to the proposed St. Johns River navigation channel deepening. The USACE contracted with Taylor Engineering to prepare an evaluation of ecological effects in the lower St. Johns River (LSJR) from the proposed deepening. The USACE directed Taylor Engineering to base the evaluation on methods developed for assessment of estuarine portions of the St. Johns River as recently described by the St. Johns River Water Management District (SJRWMD, 2012).

Potential environmental changes due to channel deepening include alteration of salinity and water circulation in the LSJR. These alterations could affect ecologically important communities in the river. This report evaluates potential effects on five of those communities — fishes, benthic macroinvertebrates, submerged aquatic vegetation, wetlands, and phytoplankton. It also examines potential effects on two key water quality parameters — dissolved oxygen and chlorophyll a. The results reported herein provide supporting documentation for the Jacksonville Harbor Deepening GRR-2 evaluation and associated Supplemental Environmental Impact Statement (SEIS).

1.2 Proposed Deepening Alternatives

The Jacksonville Harbor Deepening GRR-2 will describe in detail the proposed St. Johns River Federal navigation channel deepening alternatives. Generally, the deepening alternatives would increase the depth of the navigation channel from its currently authorized depth of 40 ft up to a maximum depth of 50 ft from the river entrance up to navigation channel mile 14 (located approximately at the northwest end of Bartram Island). Depth alternatives evaluated in this report include the current 40 ft depth and 44 ft, 46 ft and 50 ft deep channels (Figure 1.1).

1.3 Potential Ecological Changes Due to Deepening

The LSJR is an estuarine system in which salt water from the ocean mixes with fresh water flowing into the system from the upper reaches of the river and from tributaries discharging into the river.

Figure 1.1 Jacksonville Harbor Segments (Source: USACE)

Salinity in the LSJR varies from oceanic levels at the river entrance to freshwater levels in the upper river. Many of the ecological communities and individual plant and animal species inhabiting the river respond to specific salinity conditions, which set their habitat range or affect their life cycles. As water mixes and flows into and out of the river, the length of time that any particular parcel of water resides in the river also varies. The water residence time (or "water age") may also affect some ecological communities. By changing the configuration of the river channel, the proposed deepening will affect water circulation, which, in turn, affects salinity and water age. Although some estuarine communities could be affected by changes in water elevation, the proposed channel deepening scenarios would have negligible effects on water elevation. This ecological evaluation therefore, does not examine any deepening-induced water level changes.

Numerical hydrodynamic models using EFDC (Environmental Fluid Dynamics Code) provide a tool for simulating salinity concentrations and water age for the current ("baseline") condition and the proposed project alternatives. Comparison of differences from baseline that occur under simulated conditions provides a means of assessing effects of the proposed deepening on some of the salinity-dependent LSJR ecological communities.

1.4 Evaluation Methods

A recently completed St. Johns River Water Management District (SJRWMD) study of the LSJR provided the initial framework for assessing ecological impacts of salinity changes. The *St. Johns River Water Supply Impact Study* (SJRWMD 2012) evaluated ecological impacts due to water level, salinity, and water age changes that could occur under various proposed surface water withdrawal scenarios. Developed over a four-year period by a team comprised of dozens of scientists and engineers and with review by the National Research Council, the water supply impact study (WSIS) describesa set of tools ("ecological models") for ecological assessment in the lower St. Johns River.

Pertinent to the Jacksonville Harbor Deepening GRR-2 evaluation of channel deepening effects on salinity and water age, the water supply impact study (WSIS) developed ecological models to evaluate the effects of salinity and water age changes on phytoplankton, submerged aquatic vegetation, wetland, benthic macroinvertebrate, and fish communities in the LSJR. Although the WSIS focused on evaluation of the effects of changes in flow entering the upper reaches of the river, the numerical and ecological models developed for the WSIS address salinity and water age effects in the LSJR. For the channel deepening evaluation, this report reviews the WSIS ecological models and adapts them, where possible, for use in the deepening evaluation. Differences in channel configuration, geographic scope, simulation time frames, and evaluation focus meant that not all of the WSIS ecological models could be directly applied for the Jacksonville Harbor Deepening GRR-2 evaluation. Subsequent chapters in this report describe the application of the SJRWMD ecological models or alternative methods for the Jacksonville Harbor Deepening GRR-2 study.

In addition to the ecological models, the WSIS used the CE-QUAL-ICM water quality model to evaluate selected water quality parameters. Likewise, the Jacksonville Harbor Deepening GRR-2 evaluation included application of a CE-QUAL-ICM model to evaluate the same water quality parameters in the LSJR. The Jacksonville Harbor Deepening GRR-2 CE-QUAL-ICM modeling efforts are described in Appendices A and B.

This report does not address all potential environmental effects of the harbor deepening project. The SEIS prepared for the harbor deepening will include discussion of pertinent environmental effects not addressed in this report.

1.5 Geographic Scope of the Study

Though the proposed channel deepening extends about 14 miles upstream from the river mouth, salinity changes caused by the deepening could extend much further upstream. The Jacksonville Harbor Deepening GRR-2 ecological evaluation study area therefore begins at the confluence of St. Johns River and the Atlantic Ocean, and extends some 101 river miles upriver to a point slightly downstream of Lake George. The Jacksonville Harbor Deepening GRR-2 ecological study area, shown in Figure 1.2, comprises River Segments 1, 2, and 3 as defined in the WSIS (SJRWMD 2012):

Segment 1 – Mayport to Fuller Warren Bridge, river mile 0 to 24.6[1]

Segment 2 – Fuller Warren Bridge to Fleming Island, river mile 24.6 to 40.4

Segment 3 – Fleming Island to Little Lake George, river mile 40.4 to 101.3

Salinity changes due to channel deepening do not propagate upriver beyond the Shands Bridge (river mile 50) in the northern part of Segment 3 (Taylor 2012).

Figure 1.2 GRR-2 Ecological Evaluation Study Area (Source: SJRWMD, 2012)

[1] River miles cited in this report refer to the SJRWMD river miles used for ecological evaluation. This river mile system is slightly different than the USACE river miles.

Nassau, Duval, Clay, St. Johns, and Putnam counties have riverfront along the river's main channel in the study area. The paragraphs below provide a summary of river conditions in the study area.

The area near the mouth of the St. Johns River (river miles 0 - 7) includes the U.S. Naval Station at Mayport, the confluence of the Florida Intracoastal Waterway and the river immediately west of the Naval Station, extensive salt marshes north and south of the main river channel and along the intracoastal waterway north and south. The shoreline along river miles 7 to 25 (slightly upstream of the Fuller Warren Bridge) is largely urbanized, comprising the City of Jacksonville, port facilities, electric generation facilities, and other waterfront features such as dredged material management facilities.

Though largely urbanized, this area includes several tributaries and associated wetland systems, including the Trout, Broward, and Arlington Rivers, Dunn Creek and a large embayment, Mill Cove. Urbanization continues upstream from river miles 25 to 43, where much of the shoreline comprises urban or suburban communities. Within this region, tributaries include the Cedar, and Ortega Rivers, Doctors Lake, and Julington Creek with their associated wetland systems. Between river miles 43 and 68 (Federal Point) fringing swamps and marshes, farmland, and minor residential areas occur near the river shoreline. Upstream of Federal Point, the west bank of the river is dominated by farmland with expanding river edge residential development and the towns of East Palatka (about river mile 80). On the west side of the river upstream of Federal Point, areas of swampland, the confluence of Rice Creek with the river and the town of Palatka waterfront (river mile 80) are dominant shoreline features. Upstream of river mile 80 to the study area terminus, swamps and interspersed residential development are the primary shoreline land forms and uses.

From river miles 0 to 25, the main stem of the river is subject to large tidal fluctuation and strong currents. Outside of the Federal navigation channel, river depth varies with maximum depths 50 ft occurring in the downtown Jacksonville area. Upstream of downtown Jacksonville, beginning roughly at river mile 25, the river channel becomes shallow, generally less than 6.6 ft (Miller et al. 2012). Tidal range is diminished but still a notable factor affecting shoreline wetland communities. Submerged aquatic vegetation (SAV), typically dominated by eelgrass (*Vallisneria americana*), is a key ecological community that occurs commonly along the shoreline from about river mile 25 upstream. Moving upstream from river mile 25, as the water becomes fresher, a diverse submerged and emergent wetland community occurs along the shoreline where not supplanted with armoring (revetments, seawalls, etc.).

The remainder of this report is organized as follows: Chapter 2 describes the ecological evaluation framework, including the identification of the deepening alternatives, application of the hydrodynamic model that provides input data for the ecological evaluation, general applicability of the WSIS ecological models. Chapters 3 – 7 describe evaluation of each of the five ecological communities. Chapter 8 briefly discusses the water quality modeling while Appendices C and D contain separate reports of water quality modeling details. Appendix C describes the EFDC model developed to provide input data to the ICM-CEQUAL water quality model. Appendix B describes calibration of the CE-QUAL model.

2.0 ECOLOGICAL EVALUATION FRAMEWORK

2.1 Introduction

The ecological evaluation reported herein focuses on key LSJR ecological components — submerged aquatic vegetation, wetlands, fish, benthic macroinvertebrates, and phytoplankton — for which the SJRWMD WSIS provides ecological models (SJRWMD, 2012). The various ecological models were developed by the SJRWMD to evaluate the effects of water withdrawals in the upper St. Johns River from the river mouth up to Blue Cypress Lake (river mile 275). Representing the most recent and comprehensive assessment of the St. Johns River, the models addressed ecological effects of water level changes upstream of Deltona and salinity and water age changes downstream of Palatka.

Hydrodynamic modeling of the proposed Jacksonville Harbor deepening alternatives provided information about the potential effects of channel deepening on water levels and salinity (Taylor 2012). The modeling results indicated that a deeper channel would have negligible effects on riverine water levels. The WSIS models dealing with water level were thus not applicable to the harbor deepening evaluation. The hydrodynamic modeling showed that the deeper channel would alter salinity distribution in the LSJR. This ecological evaluation therefore used the WSIS report as the basis for assessing effects based on alteration of salinity patterns.

This chapter provides a brief review of the Jacksonville Harbor deepening alternatives, an overview of the WSIS model systems and review of the potential applicability of the WSIS models to the harbor deepening ecological evaluation. Subsequent chapters provide in-depth discussion about the application of the WSIS models to the harbor deepening study.

2.2 Jacksonville Harbor Deepening Alternatives

Segment 1 of the Jacksonville Harbor project, extending from the mouth of the river up to USACE river mile 14 near the northwest end of Blount Island, is authorized for 40-ft depth. The proposed Jacksonville Harbor deepening would increase the authorized depth of Segment 1. As described in the Jacksonville Harbor Deepening GRR-2 the USACE is considering and evaluating several project depth alternatives, up to a maximum depth of 50 ft. This ecological evaluation considered alternative project depths of 44 ft, 46 ft and 50 ft, comparing the effects of each of those alternatives to the project baseline condition.

The project baseline against which the deepening alternatives were compared represents the project area condition at time of construction, projected to occur in 2018. The baseline condition therefore includes river bathymetry as will exist following completion of the Mayport deepening and Mile Point project construction.

This study also included consideration of project area conditions 50 years after project completion. The 50-yr condition includes a 0.39-ft sea level rise and 155 million gallons per day (MGD) water withdrawals from the upper St. Johns River. This sea level rise represents a continuation of the recent historical rate of sea level rise. Taylor (2012) provides more detail about the deepening alternatives summarized in this section.

2.3 WSIS Model Systems

The WSIS methodology and report (SJRWMD, 2012), reviewed by the National Research Council, describes a comprehensive data set and analytical system for evaluation of the LSJR. The WSIS ecological models for the LSJR describe, in various formats, predictive relationships between salinity or water age and characteristics of the five LSJR river ecological components. Each model represented the consensus of a group of experts assembled to study a specific ecological component.

To apply the ecological models, the WSIS study group first used the Environmental Fluid Dynamics Code (EFDC) hydrodynamic model to simulate baseline and various water withdrawal scenarios. The WSIS baseline scenario represented LSJR basin conditions as existed in 1995. Forecast scenarios included several combinations of future water withdrawal, land use scenarios, and sea level rise (0.46 ft) as estimated for the year 2030. Notably, the 2030 condition included estimated land use patterns that resulted in greater water runoff and discharge into the river than occurred with the 1995 land use.

The WSIS EFDC model simulated each scenario for an 11-year period using rainfall and evapotranspiration records from 1995 through 2005. Allowing for a one-year "spin-up" period, the WSIS study group based its evaluations on the simulation results for the 10-year period from 1996 – 2005.

Output from the EFDC model simulations provided salinity and water age data for application of the ecological "models". The ecological models developed by the WSIS study team employed differing evaluative approaches which depended on the particular derivatives of salinity or water age that best described observed ecological effects. Briefly, the five ecological models evaluated effects based on the following approaches:

- Submerged aquatic vegetation – frequency and spatial extent of salinity stress on eelgrass (*Vallisneria americana*)
- Wetlands – location of salinity values defining transitions between wetland community types
- Fish – distribution of species or "pseudospecies" in relation to freshwater inflows
- Benthic macroinvertebrates – distribution of species in relation to salinity zones
- Plankton – regression equations using water age statistics as independent variables to calculate phytoplankton bloom metrics

Comparison of the modeled differences in ecological community indicators among baseline and water withdrawal scenarios allowed the WSIS study team to make quantitative or qualitative estimates of the magnitude of effects due to the withdrawals. Subsequent chapters of this report review of each of the five WSIS ecological models and discuss their applicability for the Jacksonville Harbor Deepening GRR-2 study.

2.4 Jacksonville Harbor Deepening Ecological Evaluation Approach

The Jacksonville Harbor Deepening ecological evaluation began with review of the WSIS models to determine how they could be applied to predict the effects of salinity and water age changes in the river due to the deepening. Initial EFDC modeling of the harbor deepening project showed that the project would not alter salinity patterns upstream of the Shands Bridge in WSIS River Segment 3. Each of the five WSIS models provided methods for assessing impacts of salinity or water age changes in one or more of River Segments 1 – 3. The deepened channel would not alter water levels, land use, runoff, nutrient loading, or other factors considered in the WSIS study. Application of the WSIS models for salinity and water age changes therefore formed the starting point for the Jacksonville Harbor Deepening GRR-2 ecological evaluation.

The ecological evaluation approach adopted for the Jacksonville Harbor Deepening GRR-2 ecological modeling is based on the WSIS model approaches, with some differences intended to give a more conservative (i.e., overestimate) assessment of potential impacts. Similar to the WSIS, the Jacksonville Harbor Deepening GRR-2 ecological modeling begins with EFDC model simulations of project baseline and several project alternative scenarios. The following paragraphs summarize the Jacksonville Harbor Deepening GRR-2 EFDC model simulations. Taylor (2011, 2012) provides additional technical details and model results.

The EFDC model is a three-dimensional numerical model with the ability to simulate flow and transport in surface water systems. As applied for the Jacksonville Harbor Deepening GRR-2 ecological evaluation, the model contains 4,824 horizontal cells with six vertical layers in each cell. The model domain extends from the Atlantic Ocean near the river mouth upstream to the south end of Lake George (Figure 2.1).

The SJRWMD provided the EFDC model from the WSIS study, including all boundary conditions data. Taylor Engineering modified the model for application with the Jacksonville Harbor Deepening GRR-2 study. Notable modifications include repositioning the southern model boundary at Lake George, adding model cells along the project area navigation channel, and adding depths based on USACE bathymetric surveys conducted in 2009/10 and the design depths of the Mayport Deepening and the Mile Point Projects. These changes were made to focus the model on the LSJR portion of the river where deepening effects will occur, to better define the river bathymetry in the project area, and to provide a "baseline" condition that represents the river bathymetry at the anticipated time of the Jacksonville Harbor deepening.

Each of the Jacksonville Harbor Deepening GRR-2 EFDC model simulations included the following conditions:

- 1995 land use condition and inflows associated with that condition
- 7-year simulation period (1995 – 2001)
- Boundary condition input data as provided by the SJRWMD

The selected seven-year simulation period includes the three driest consecutive years (1999 – 2001) recorded for the LSJR basin. Selection of this time period thus provides a conservative estimate of salinity impacts in that the dry conditions should allow increases in salinity farther up the river than under a more typical rainfall period. Taylor (2012) provides additional discussion of these model details.

Table 2.1 identifies the eight conditions simulated for the Jacksonville Harbor Deepening GRR-2 ecological modeling study and identifies the combination of project, water withdrawal, and sea level condition represented by each simulation. We ran all simulations for a 7-year period from 1995 – 2001.

Allowing 1995 to be a spin-up year, the model results from 1996 to 2001 were saved in output data files for use in the ecological models. Each simulation output file contained hourly results for each of the vertical layers in each of the model cells. As discussed in succeeding chapters, we applied post-processing routines to the output data to generate the specific salinity or water age data required by the ecological models.

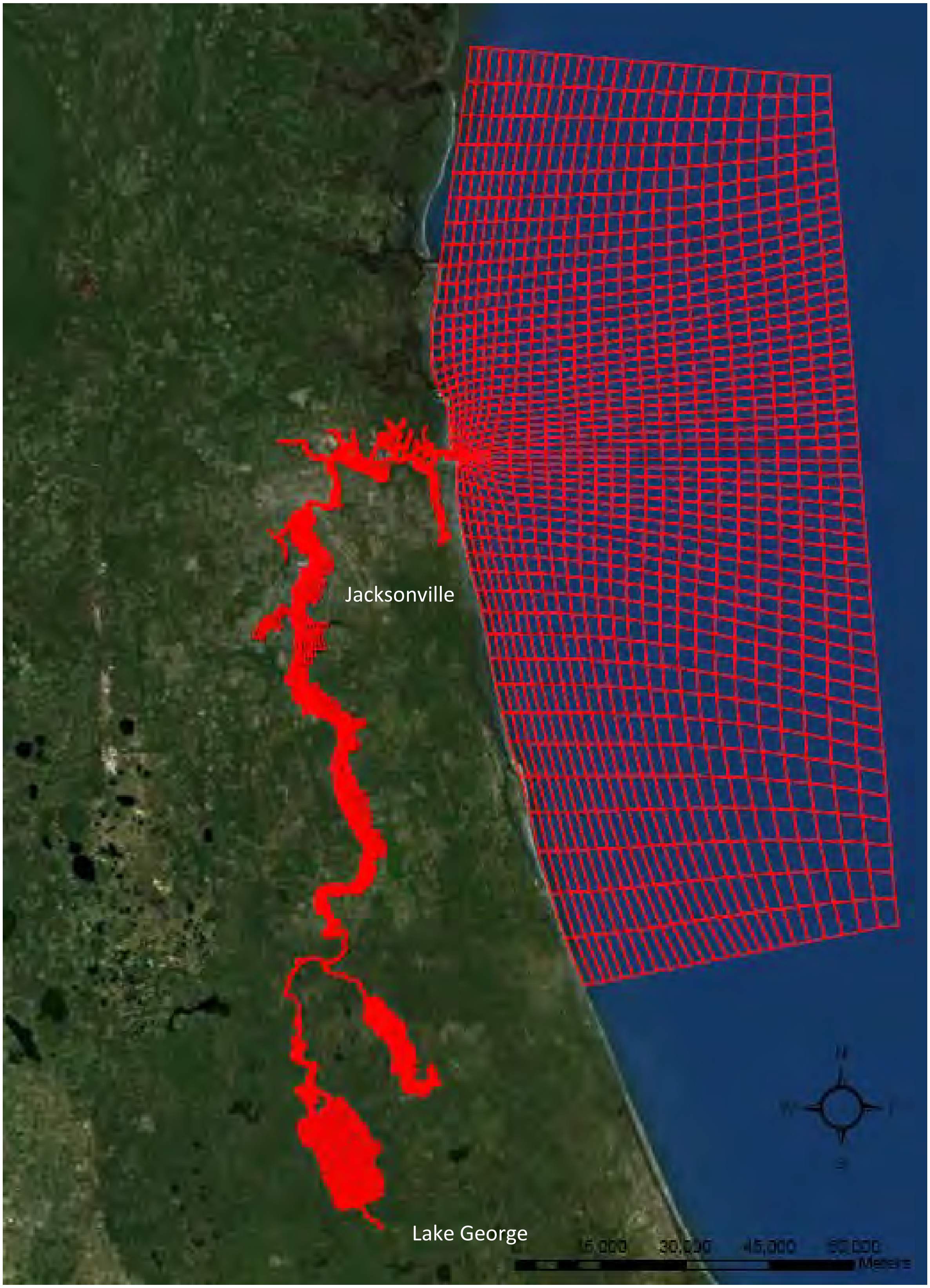

Figure 2.1 EFDC Model Mesh

Table 2.1 EFDC Model Simulations

Scenario	Depth (ft)				Water Withdrawal		Sea Level	
	40	44	46	50	None	155 MGD	No Change	Const. +50 yr, Curve 1 (0.39 ft)
40ft_B95_SL0[1]	x				x		x	
40ft_FSJ_SF1	x					x		x
44ft_B95_SL0		x			x		x	
44ft_FSJ_SF1		x				x		x
46ft_B95_SL0			x		x		x	
46ft_FSJ_SF1			x			x		x
50ft_B95_SL0				x	x		x	
50ft_FSJ_SF1				x		x		x

[1]Baseline condition

The Jacksonville Harbor Deepening GRR-2 ecological evaluation based on the WSIS analytical models was not intended to address all potential environmental effects of the deepening project. Other ongoing USACE efforts, including preparation of a Supplemental Environmental Impact Statement (SEIS) for the Jacksonville Harbor Deepening, will address other project effects.

The WSIS models were designed to address ecological effects in the main stem (including along the shoreline) of the LSJR. Identification of effects in the main stem may allow inference of potential effects upstream of the model domain; the model systems do not, however, directly address impacts of salinity changes that may occur upstream in marshes and tributaries.

The EFDC model configuration used for the Jacksonville Harbor Deepening GRR-2 study was well-calibrated to simulate salinity conditions in the LSJR. However, because the EFDC model domain and simulation period were not identical to those used for the WSIS, some of the ecological models— wetlands and phytoplankton in particular — did not perform well under the simulation conditions set for the Jacksonville Harbor Deepening GRR-2 study. The results from these two model systems suggested that the models are highly specific for the particular EFDC configuration used in the WSIS study. Consequently, we adapted and modified as practicable the model concepts for the Jacksonville Harbor Deepening GRR-2 evaluation. Subsequent chapters of this report describe all of the ecological model approaches, application, and results in detail.

3.0 SUBMERGED AQUATIC VEGETATION

The WSIS submerged aquatic vegetation (SAV) working group evaluated potential effects of water withdrawal on SAV communities of the St. Johns River. Dobberfuhl et al. (2012) describe the working group's SAV evaluation and development of the SAV evaluation "models." This chapter reviews aspects of Dobberfuhl et al. (2012) report, identifies the model's applicability for evaluation of effects of the Jacksonville Harbor deepening project, and describes application of the model for the Jacksonville Harbor Deepening GRR-2 evaluation.

The submerged aquatic vegetation community (SAV) in the LSJR is dominated by *Vallisneria americana*, with other oligohaline/freshwater species — including *Najas guadalupensis*, *Ruppia maritima*, and others — observed on a less-frequent basis. The downstream extent of the LSJR SAV community occurs in the vicinity of river mile 25 near the Fuller Warren Bridge. SAV is sparsely distributed in that lower end of its range and its distribution varies from year to year. SAV become more abundant and dense upstream, with persistent beds occurring at a SJRWMD monitoring station near the Bolles School at about river mile 31. The Bolles School monitoring station likely represents the most downstream extent of persistent SAV beds in the LSJR. SJRWMD monitoring shows that SAV from the Bolles School site upstream to a monitoring station at Moccasin Slough near river mile 37 is subject to periodic salinity stress, which affects both distribution and abundance. SAV in this area is also subject to low-light stress due to higher water coloration during high runoff conditions.

3.1 WSIS SAV Model

For the WSIS, Dobberfuhl et al. (2012) determined that the two most important potential effects of water withdrawal on SAV communities relate to (1) alterations to stage (water levels) and (2) elevated salinity. Given its cosmopolitan nature, dominance in the estuarine portions of the river, biological importance, and well-studied physiology and ecology, the working group used *Vallisneria americana* as the representative species for all SAV analyses. Because the proposed Jacksonville Harbor deepening does not alter water levels affecting SAV, the water level effects model is not applicable to the Jacksonville Harbor Deepening GRR-2 study. This report therefore focusses on application of the WSIS SAV salinity stress model.

The WSIS SAV working group used existing literature to develop the salinity exposure model and performed additional field and experimental analyses (i.e., microcosm experiments, intensive SAV sampling, and in situ reciprocal transplant experiments) to further refine the stress thresholds within the model. The group found that salinity stress on *V. Americana* depends on both salinity level and duration of exposure, as illustrated in Figure 3.1[2]. The working group found that 7-day and 30-day average salinity best predicted salinity stress on *V. Americana* and used these indicators to evaluate the modeled salinity changes due to water withdrawal.

The WSIS salinity stress model compared EFDC salinity output (daily average salinity for surface cells within the model domain) to the stress levels shown in Figure 3.1. The model considered salinity only in River Segments 2 and 3, from river miles 24.5 to 48 (Fuller Warren Bridge to Green Cove Springs) and only in littoral zone cells (i.e., those contiguous to the shoreline). This area, described by 140 model cells, represents the downstream limit of *V. Americana* habitat in the LSJR. Frequent salinity stress prevents occurrence of the species farther downstream in River Segment 1. The model littoral cells represent the shallow shoreline habitat where *V. americana* may grow in this area.

Each model cell was assigned a daily stress condition four stress categories defined in the SAV salinity exposure model. From the resulting data, the Dobberfuhl (2012) calculated both frequency and total acreage of salinity stress on potential SAV habitat.

3.2 Application of the SAV Model for Jacksonville Harbor Deepening GRR-2 Ecological Effects Evaluation

Initial review of EFDC simulation results indicated that the salinity changes due to the harbor deepening would not reach Green Cove Springs. We therefore elected to evaluate SAV stress in the same 140 modeled cells as the WSIS study. Figure 3.2 shows the SAV model cells, which cover 13,947 acres. These cells represent potential littoral zone SAV habitat. SAV has historically occurred along the shoreline within the area covered by these cells. However, SAV is absent from some of the cells when stressed by salinity or other factors. In addition, as noted by the WSIS SAV study group, the model cell widths are four to six times greater than the observed widths of SAV beds so the total area of potential seagrass habitat equals less than 13,947 acres. In considering the number of acres affected by salinity stress, the WSIS study group multiplied the modeled acreage by a factor of 0.25 to obtain a more likely estimate of affected acreage.

From the EFDC simulation output files, we calculated the daily, vertically averaged salinity for each of the 140 littoral zone model cells. From those values, we calculated the 7-day, 30-day, and 90-day

[2] Figures referenced in this chapter appear at the end of the chapter.

average salinity[3] in each cell for each day of the simulation period. Comparing the salinity values to the WSIS salinity-duration exposure model we classified the daily stress level in each of the cells as no effect, low stress, moderate stress, or extreme stress. The results indicated that SAV would experience the greatest number of days under a stressed condition when stress was determined by the 90-day average salinity. The results presented below are based on SAV stress assessment from 90-day average salinity values. With the first 90-day average value occurring on day 90 of the simulation period, this salinity data set contained 2,103 daily values for each cell for the six-year simulation period. From this data set we examined several measures of spatial and temporal distribution of SAV stress conditions. For each model cell, we calculated the stress frequency as percentage of simulation time the cell was in one of the four stress conditions and magnitude of stress frequency increase as the difference between stress frequency values for different simulation conditions. We summed the total acres in each stress category for each day of the simulation and then determined cumulative probability of the number of acres falling within each category. Lastly, we calculated the number of acre-days in a stress condition by summing the total number of acres under each stress condition and dividing by the total number of days that condition occurred in one or more cells[4].

3.3 SAV Model Results

Figure 3.3 illustrates the percentage of time each of the littoral cells is under moderate/extreme/stress for the modeled baseline 40-ft condition. As expected, the most downstream cells, near the Fuller Warren Bridge, exhibit the greatest time under stress. Ten cells in this area are under salinity stress for greater than 30% of the simulation period (1996 – 2001). About three miles upstream, near river mile 28, stress frequency decreases to 20% or less of the simulation period. Near the Bolles School SJRWMD SAV monitoring site, the model predicts salinity stress during about 10% of the simulation period. Moving upstream, stress frequency continues to decrease. Stress frequencies of 1 – 5% occur south of river mile 32 (near Naval Air Station (NAS) Jacksonville). The model-predicted stress frequency drops to 0% on the west side of the river at the Buckman Bridge (river mile 34). The 0% stress frequency zone begins at about river mile 35 on the east side of the river.

Figures 3.4, 3.5 and 3.6 show the percentage of time each of the littoral cells is under moderate/ extreme stress for the modeled 44-ft, 46-ft, and 50-ft project conditions. The model predicts little change

[3] e.g., The first 7-day average salinity value occurred on day 7 of the simulation and was the average of the daily salinities from days 1 – 7.

[4] Acres/day in a stress condition = $\sum_{d=1}^{n}$ acres /n, where d = simulation day, n = total number of days, and acres = total number acres under stress condition on the nth day.

in the area of the LSJR subject to no salinity stress for any of the simulated project conditions. The only change in the no stress area occurs, with all project alternatives, on the west side of the river immediately south of the Buckman Bridge (river mile 34 – 35) where two cells change from no stress to the 1 – 5% stress category. Downstream of the Buckman Bridge, stress frequencies progressively increase with increased simulated channel depths.

Figures 3.7, 3.8, and 3.9 illustrate the magnitude of salinity stress frequency increase in each cell for the 44-ft, 46-ft, and 50-ft project conditions relative to the baseline condition. Stress frequency increase is shown as the number of percentage points difference from the baseline condition (e.g. if the stress frequency increases from 12% for baseline to 16% for a project condition, the stress magnitude increase is 4). Given the 2,103 daily salinity data points for each six-year simulation, an increase of one percentage point equates to 3.5 days of stress per year.

For the 44-ft project simulation, salinity stress frequency increases 1 to 2 percentage points from the no stress zone downstream to about river mile 28. Downstream of river mile 28, stress frequency increases 1 to 3 points to about river mile 25. Five cells near river mile 25 and the Fuller Warren Bridge experience 4 to 6 point increases in stress frequency. The 46-ft project simulation showed several more cells from river mile 26 to 29 having up to a 3-point increase in stress frequency, along with the cells near the Fuller Warren Bridge having greater magnitude stress frequency increase. With the 50-ft project depth salinity stress frequency increased up to eight percentage points at one cell near the Fuller Warren Bridge. Increases in stress percentage of up to four points occur in several cells between the Fuller Warren Bridge and NAS Jacksonville.

Figure 3.10 shows the percentage of time each of the littoral cells is under moderate/extreme stress for the 50-yr baseline condition (i.e., 40 ft depth, 0.39 ft sea level rise, 155 MGD water withdrawal). The model shows that the no stress zone moves about one mile upriver relative to its location for the baseline 40-ft simulation. The most apparent increase in salinity stress frequency occurs between the Fuller Warren Bridge and river mile 29.

Figures 3.11, 3.12 and 3.13 show the percentage of time each of the littoral cells is under moderate or extreme stress for the 50-yr 44-ft, 46-ft, and 50-ft project conditions. For each of these projects, SAV would not experience salinity stress upstream of Doctors Lake (river mile 37).The northern extent of the no stress zone occurs about a mile upstream of its location for the 50-yr baseline condition. With all three project depths, all cells downstream of river mile 29 experience salinity stress frequencies greater than 20%.

Figures 3.14 illustrates the magnitude of salinity stress frequency increase in each cell for the 50-yr 40-ft baseline relative to the current baseline condition. Stress frequency generally increases 1 – 3 percentage points from the Fuller Warren Bridge upriver to river mile 35, with scattered cells showing up to a 4 point increase.

Figures 3.15, 3.16, and 3.17 illustrate the magnitude of salinity stress frequency increase in each cell for the 50-yr 44-ft, 46-ft, and 50-ft projects relative to the 50-yr 40-ft baseline. The magnitude of stress frequency increase is generally greater with the projects at the 50-yr time horizon than it is under the current project conditions.

Figures 3.18 – 3.21 illustrate the probability of total littoral acres in each of the stress categories for the baseline and 44-ft, 46-ft, and 50-ft project depths. These figures indicate that the greatest difference in acres subject to salinity stress between baseline and the three project conditions occurs when salinity stress begins to noticeably increase at about the 50%, 35% and 5% probability levels.

Figures 3.22 – 3.25 illustrate the probability of total littoral acres in each of the stress categories for the current baseline, 50-yr baseline and 50-yr 44-ft, 46-ft, and 50-ft project depths. The overall patterns are similar to the current conditions but differences among project alternatives are greater at the 50-yr condition.

Figures 3.26 – 3.29 show the temporal distribution of salinity stress effects in terms of total acres in each stress condition for the baseline and 44-ft, 46-ft, and 50-ft projects. Figures 3.30 – 3.33 show the same plots for the 50-yr condition. Both sets of figures illustrate that the total number of acres of potential littoral habitat affected by salinity stress varies from year to year. During relatively dry years (e.g., 1999, 2000, 2001), moderate to extreme salinity stress may occur continuously for several months under all of the simulated conditions, including the baseline and 50-yr baseline.

Table 3.1 summarizes the SAV results in terms of acres/day under salinity stress. As noted by the WSIS study group, a more likely estimate of affected acreage may be obtained by multiplying these by a factor of 0.25. The acres/day measure provides a simple means to compare total SAV stress effects of the different simulated conditions. However, these numbers do not consider the spatial and temporal distributions of salinity stress, which are important factors in determining actual effects of salinity on SAV beds. As the duration or frequency of salinity stress increases, the ability of SAV to recover from the stress would diminish.

The results of the baseline simulation indicate temporally and spatially variable salinity stress on SAV populations from the Fuller Warren Bridge to approximately NAS Jacksonville. Long (up to several months), widespread periods of salinity stress occur during the driest modeled years. These results appear consistent with field observations of declines in SAV beds during recent dry years. Increasing the channel depth causes progressively greater salinity stress superimposed on the already variable patterns of the baseline condition. Generally, the differences due to the project alternatives are much less than the annual differences due to variable hydrologic conditions. Nonetheless, the additional stress imposed by any of the proposed project alternatives will likely contribute to upstream migration of the northern extent of SAV in the LSJR.

Table 3.1 Salinity Stress Acres/Day

Stress Condition	Acres/day							
	Current Condition				50-yr Condition			
	Base 40 ft	44 ft	46 ft	50 ft	Base 40 ft	44 ft	46 ft	50 ft
No Effect	10,983	10,845	10,826	10,764	10,627	10,303	10,282	10,212
Low	2,721	2,739	2,738	2,754	3,014	3,077	3,074	3,088
Moderate	1,378	1,407	1,410	1,402	1,553	1,591	1,597	1,606
Extreme	298	389	401	446	380	582	604	664

Due to the annual salinity stress variability inherent in the system, it is difficult to predict specific project induced alterations in potential SAV habitat. Nonetheless, the potential SAV habitat acreages subject to salinity stress conditions can provide a measure of impact. As noted by the Dobberfuhl (2012), the acreages obtained from the SAV model system overestimate the amount of potentially affected SAV habitat.

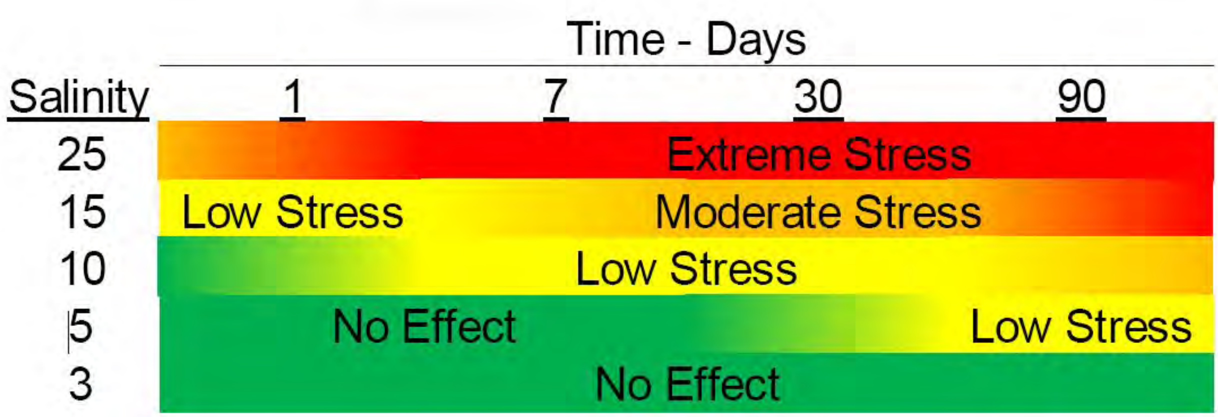

Figure 3.1 WSIS *V. americana* Stress Levels (Source: Dobberfuhl 2012)

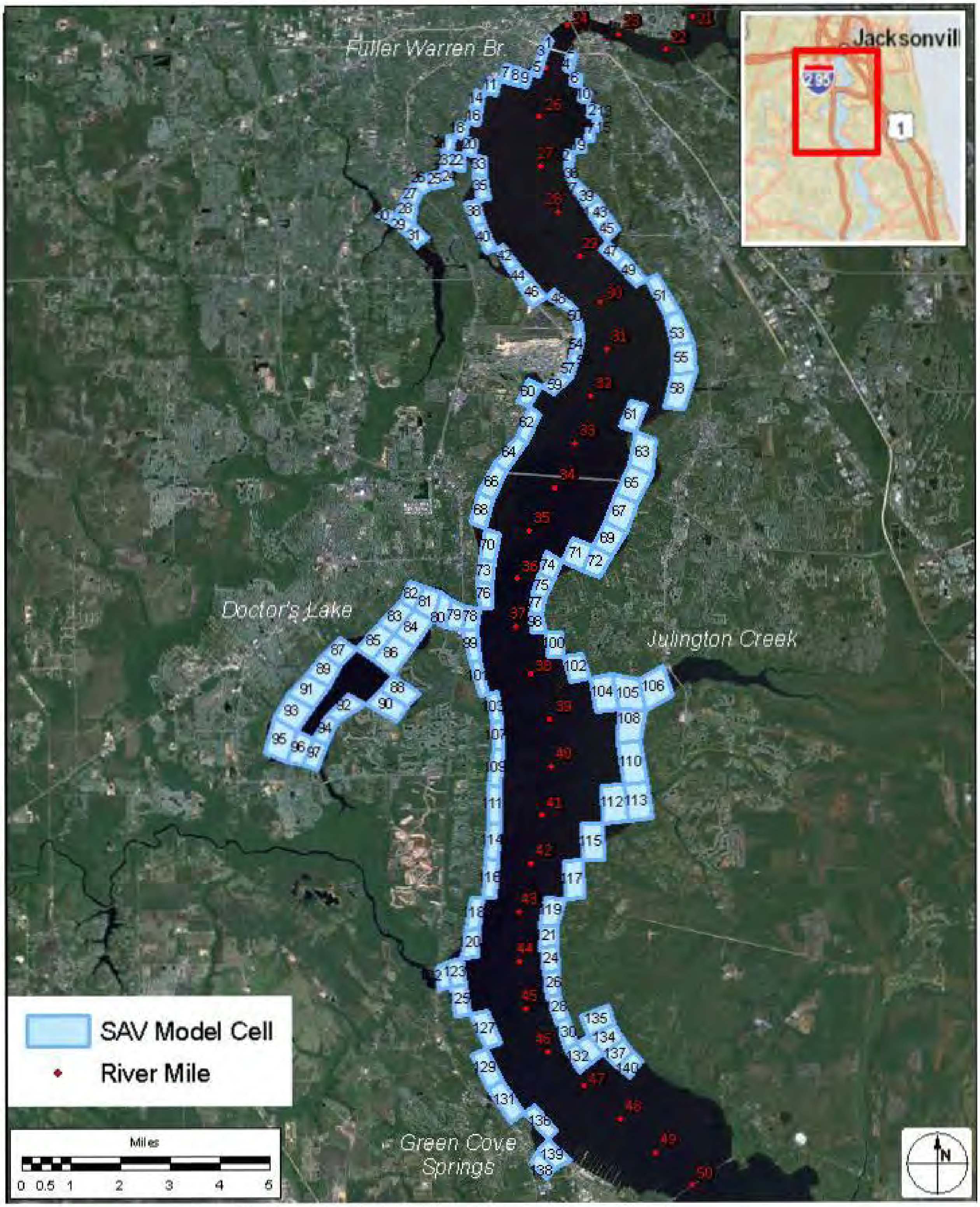

Figure 3.2 SAV Evaluation Cells

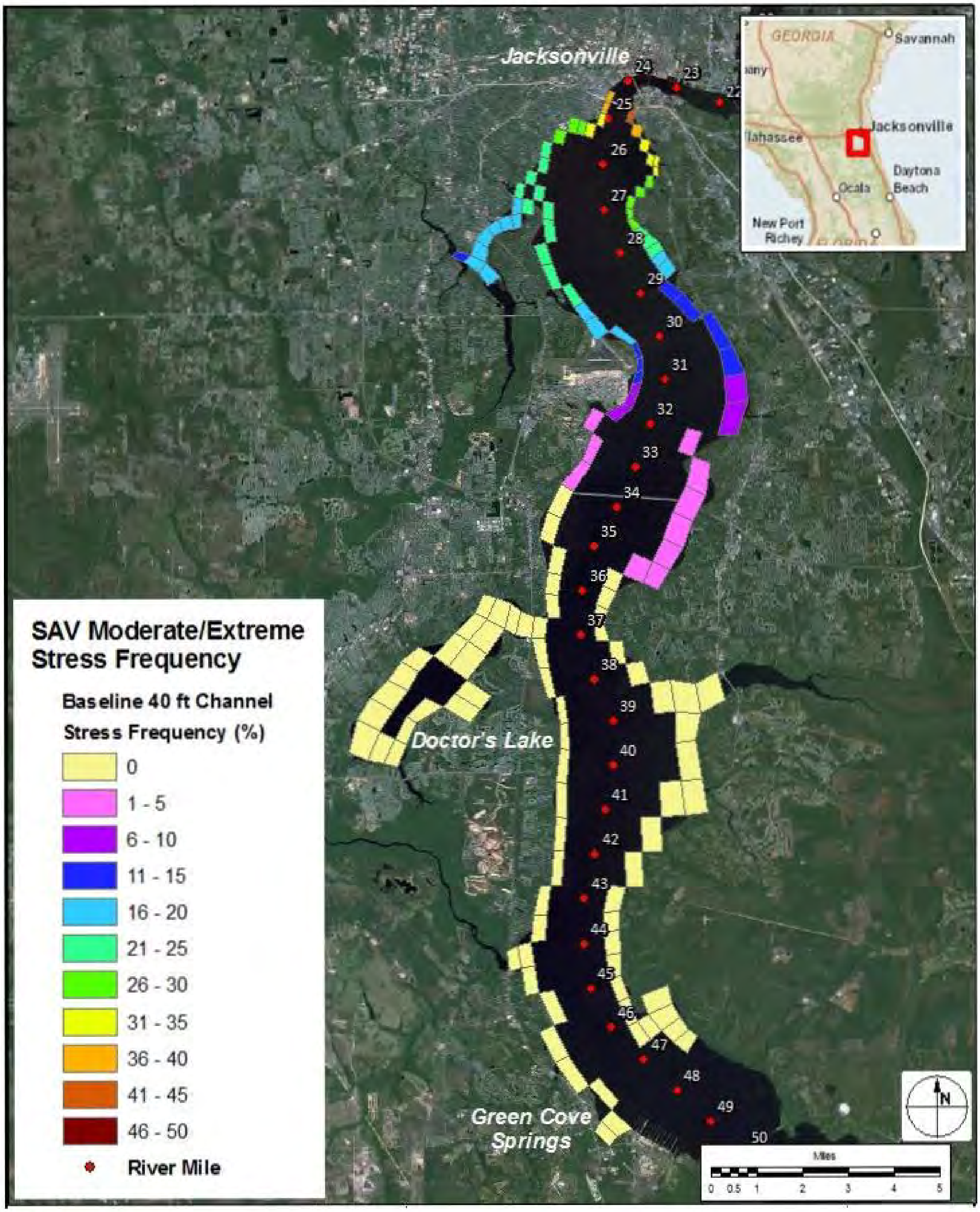

Figure 3.3 Frequency of Moderate or Extreme SAV Stress — 40-ft Baseline

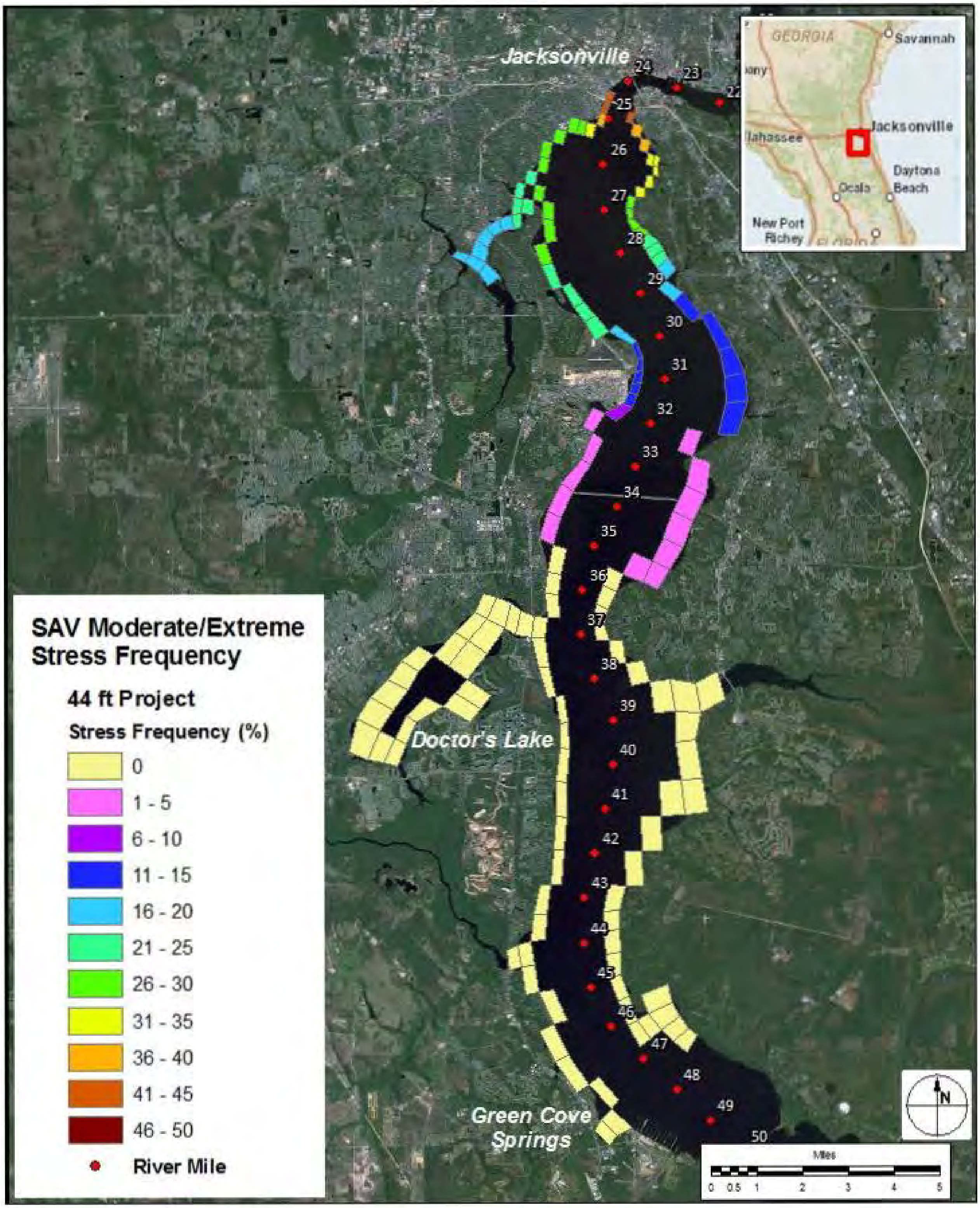

Figure 3.4 Frequency of Moderate or Extreme SAV Stress — 44-ft Project

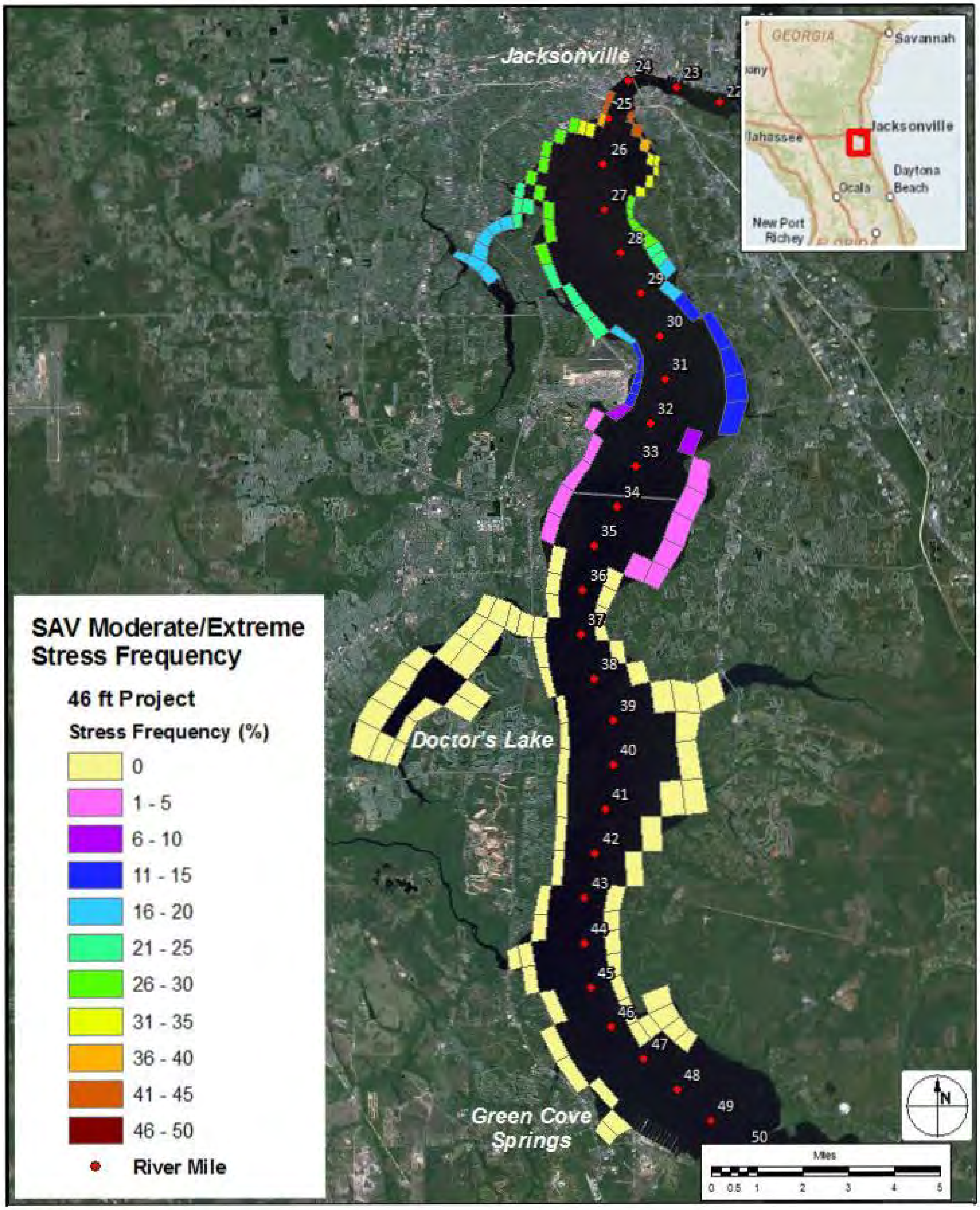

Figure 3.5 Extreme Frequency of Moderate or Extreme SAV Stress — 46-ft Project

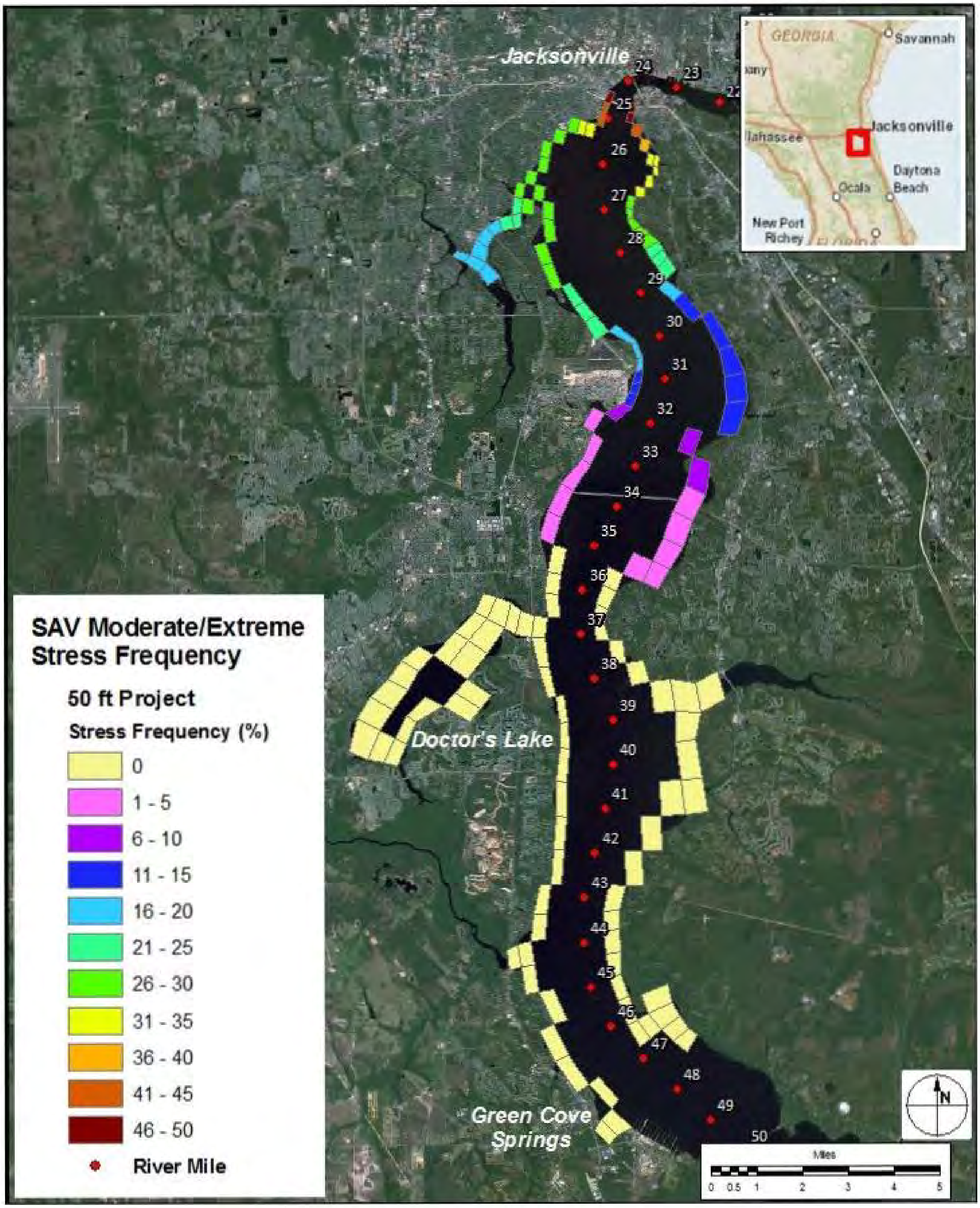

Figure 3.6 Frequency of Moderate or Extreme SAV Stress — 50-ft Project

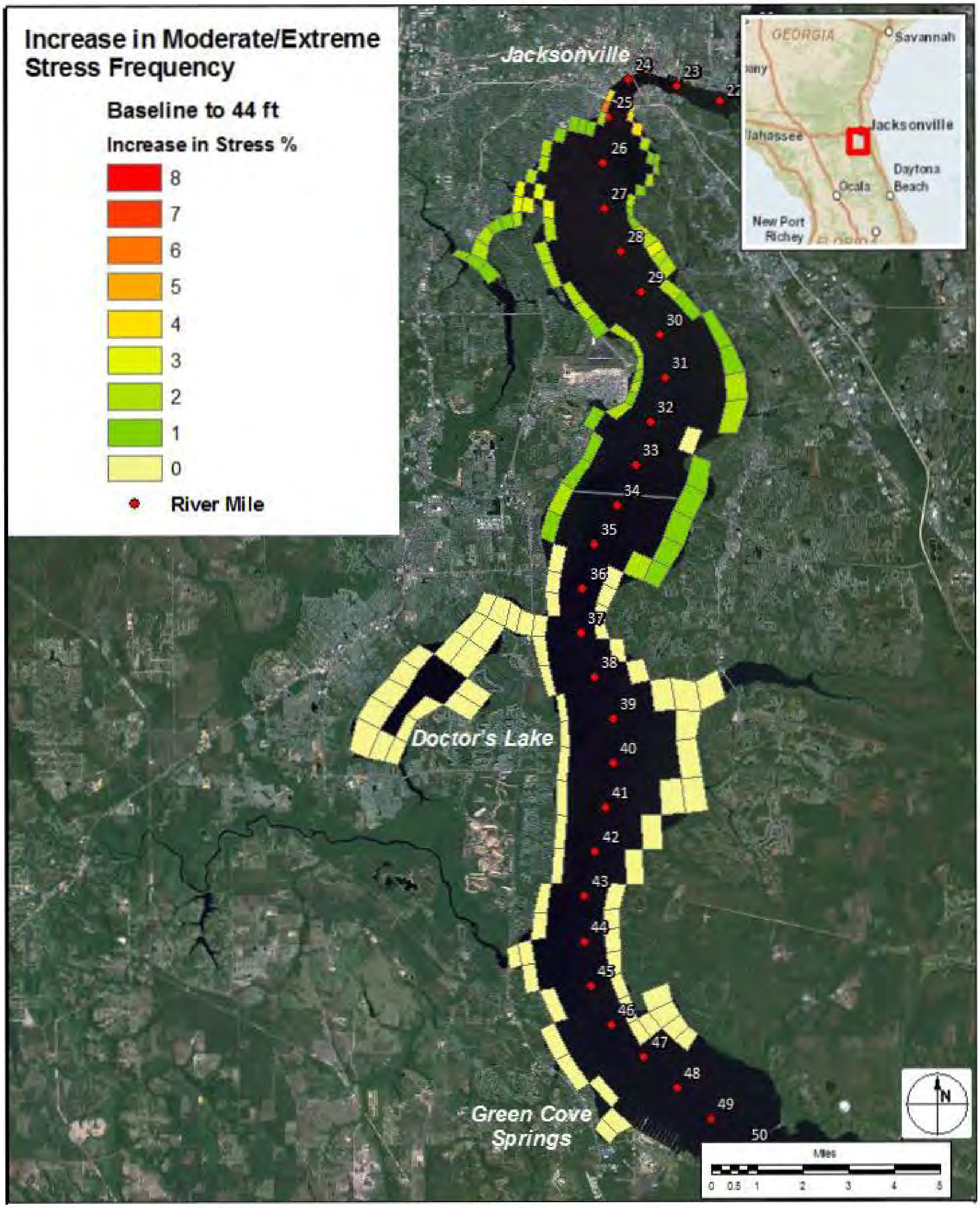

Figure 3.7 Increase in Moderate/Extreme SAV Stress — Baseline to 44-ft Project

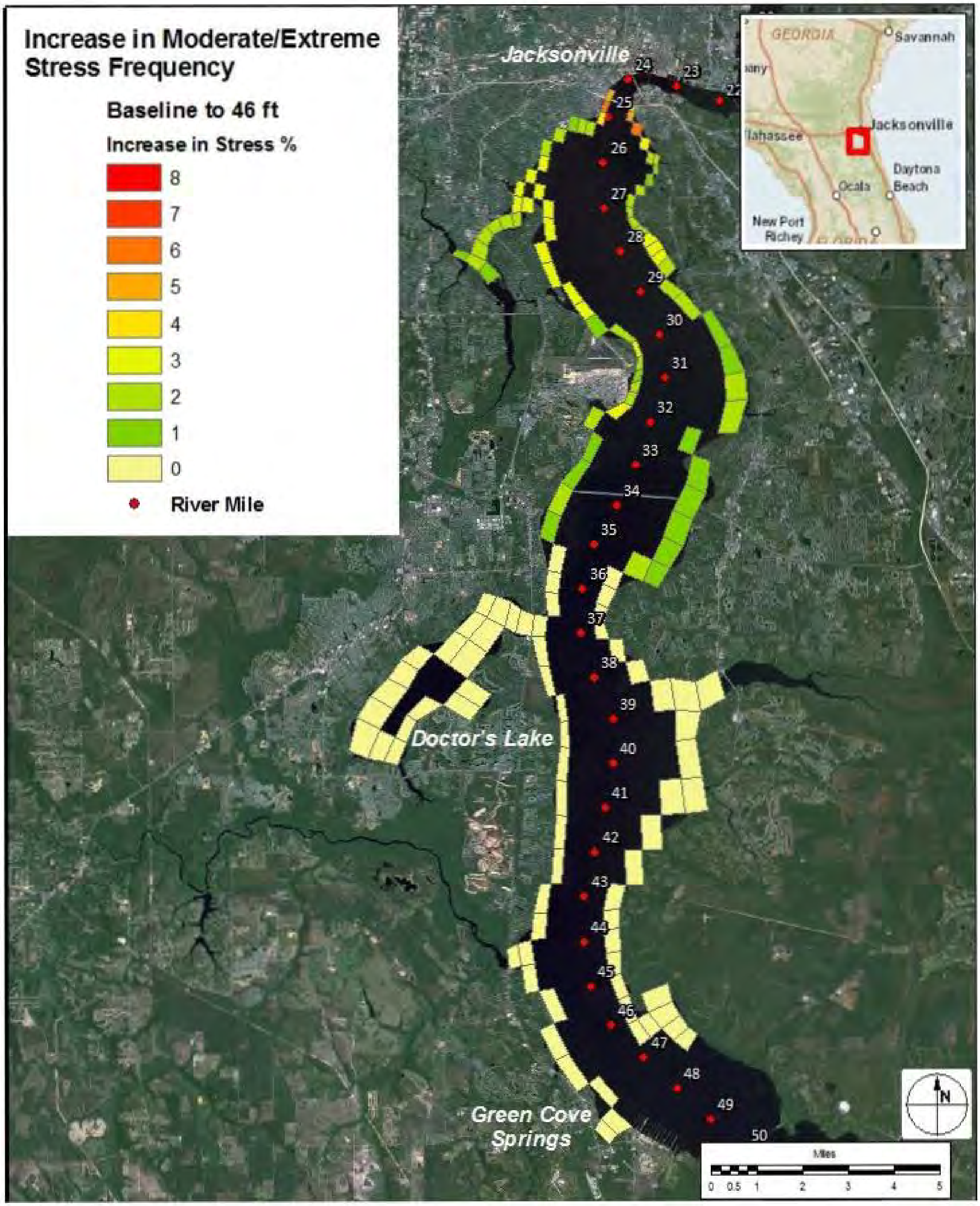

Figure 3.8 Increase in Moderate/Extreme SAV Stress — Baseline to 46-ft Project

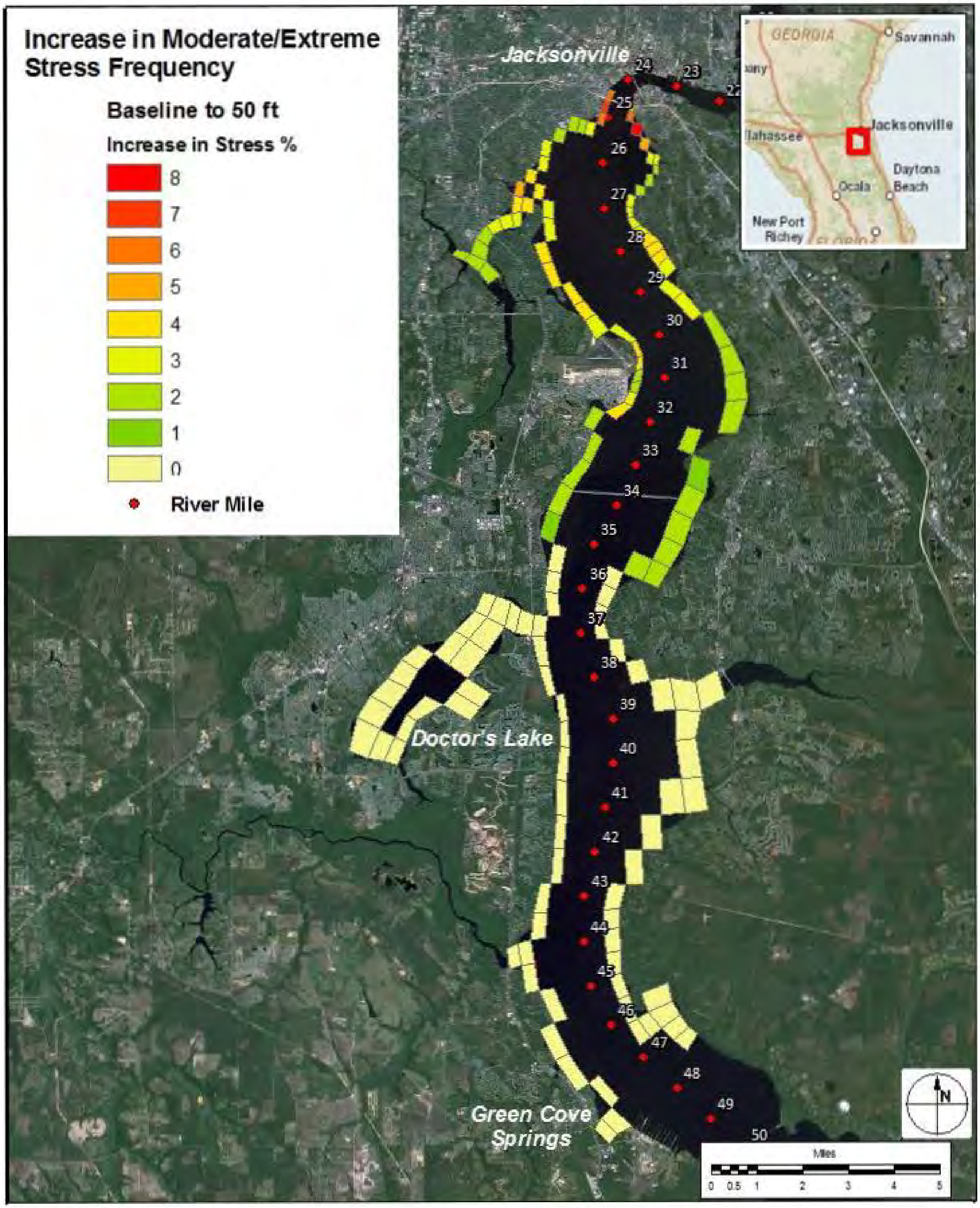

Figure 3.9 Increase in Moderate/Extreme SAV Stress — Baseline to 50-ft Project

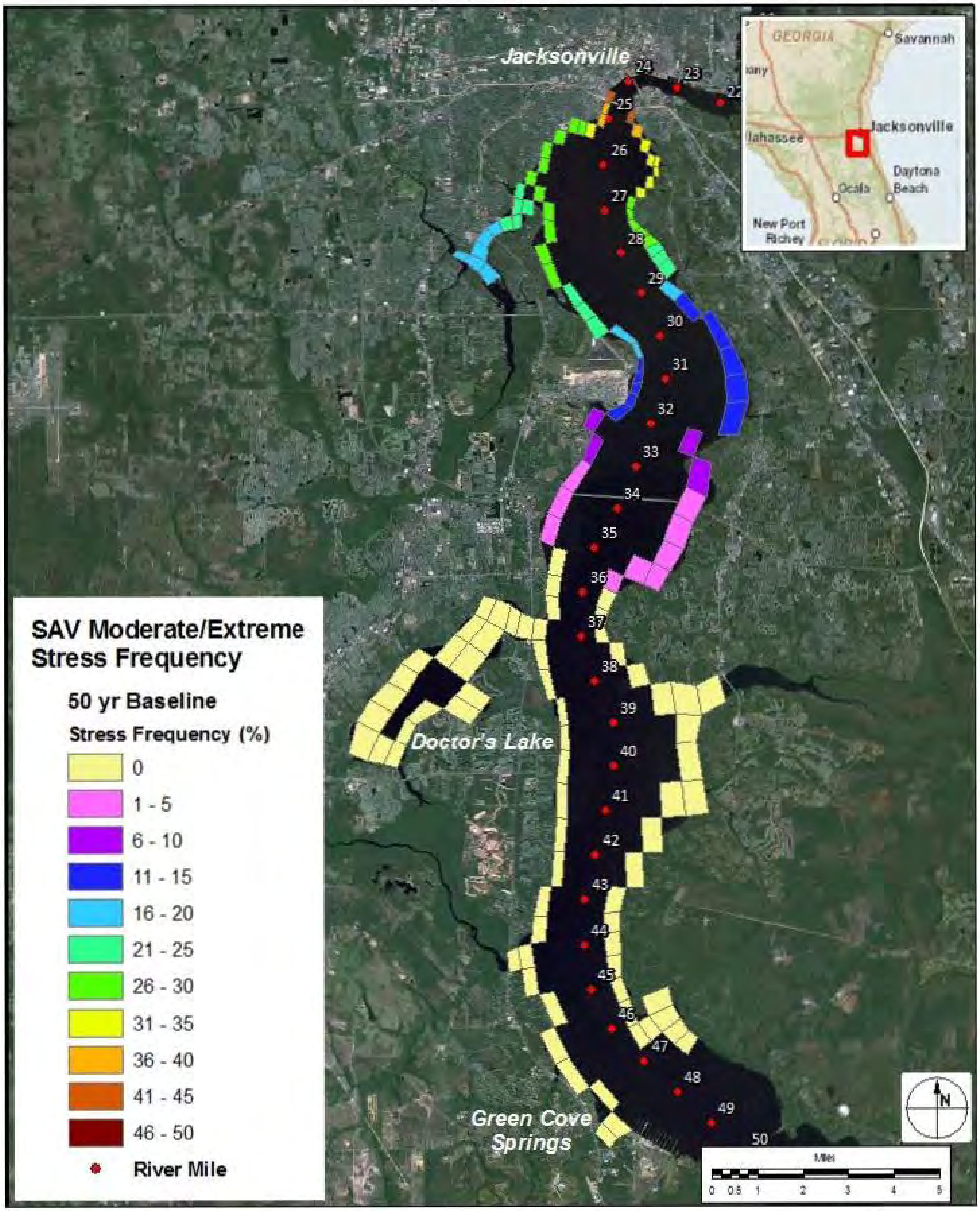

Figure 3.10 Frequency of Moderate/Extreme SAV Stress — 50-yr, 40-ft Baseline

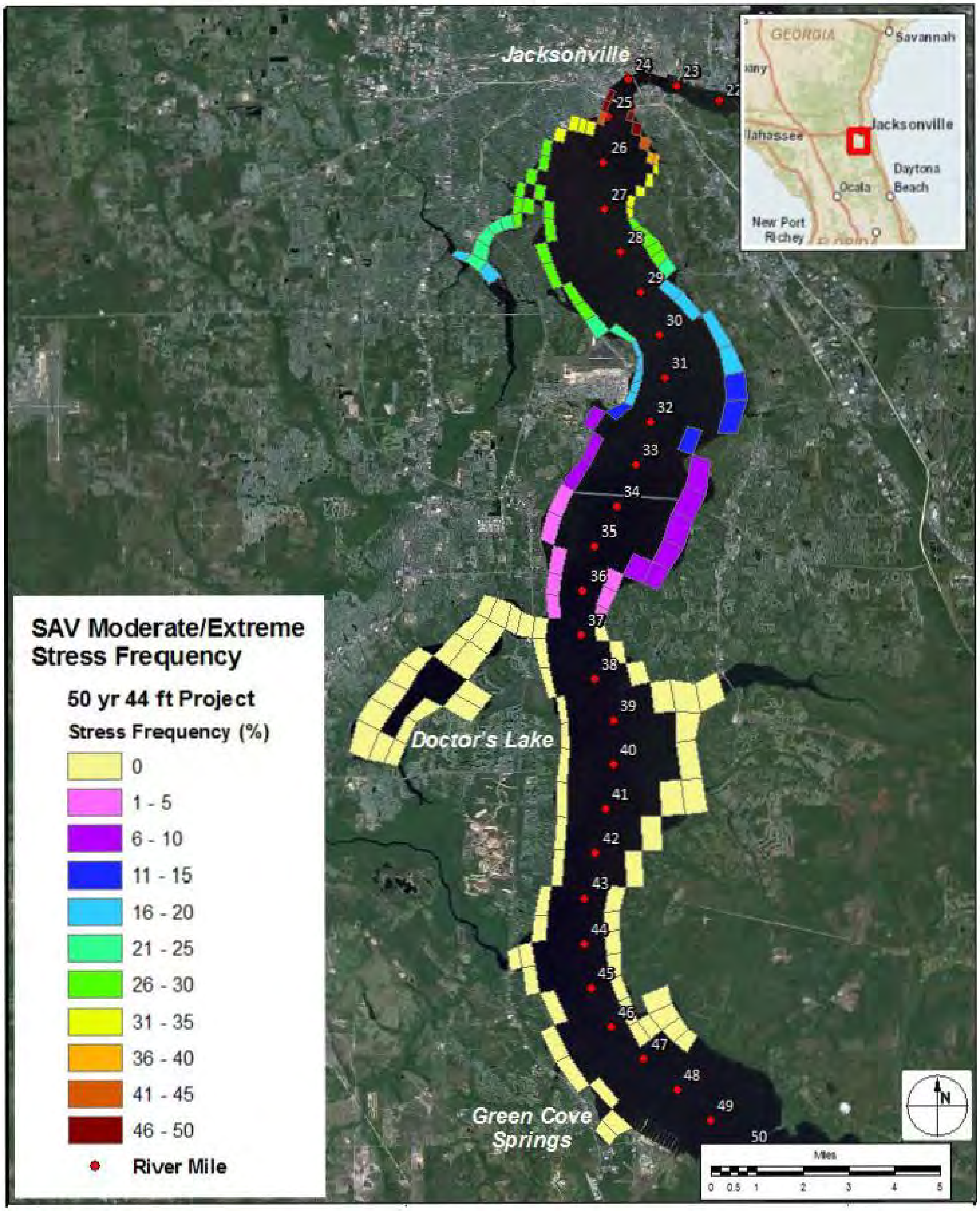

Figure 3.11 Frequency of Moderate/Extreme SAV Stress — 50-yr 44-ft Project

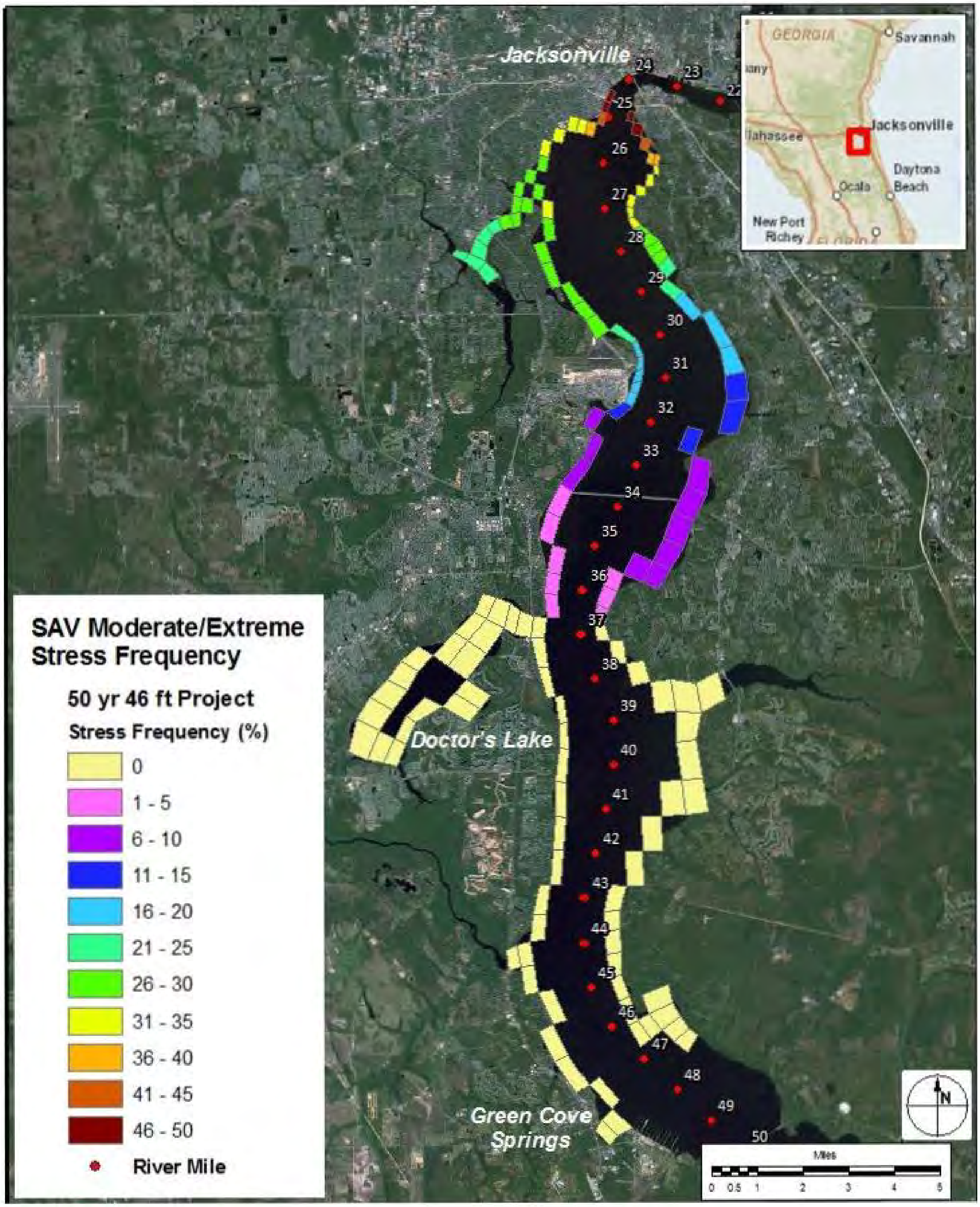

Figure 3.12 Frequency of Moderate/Extreme SAV Stress — 50-yr, 46-ft Project

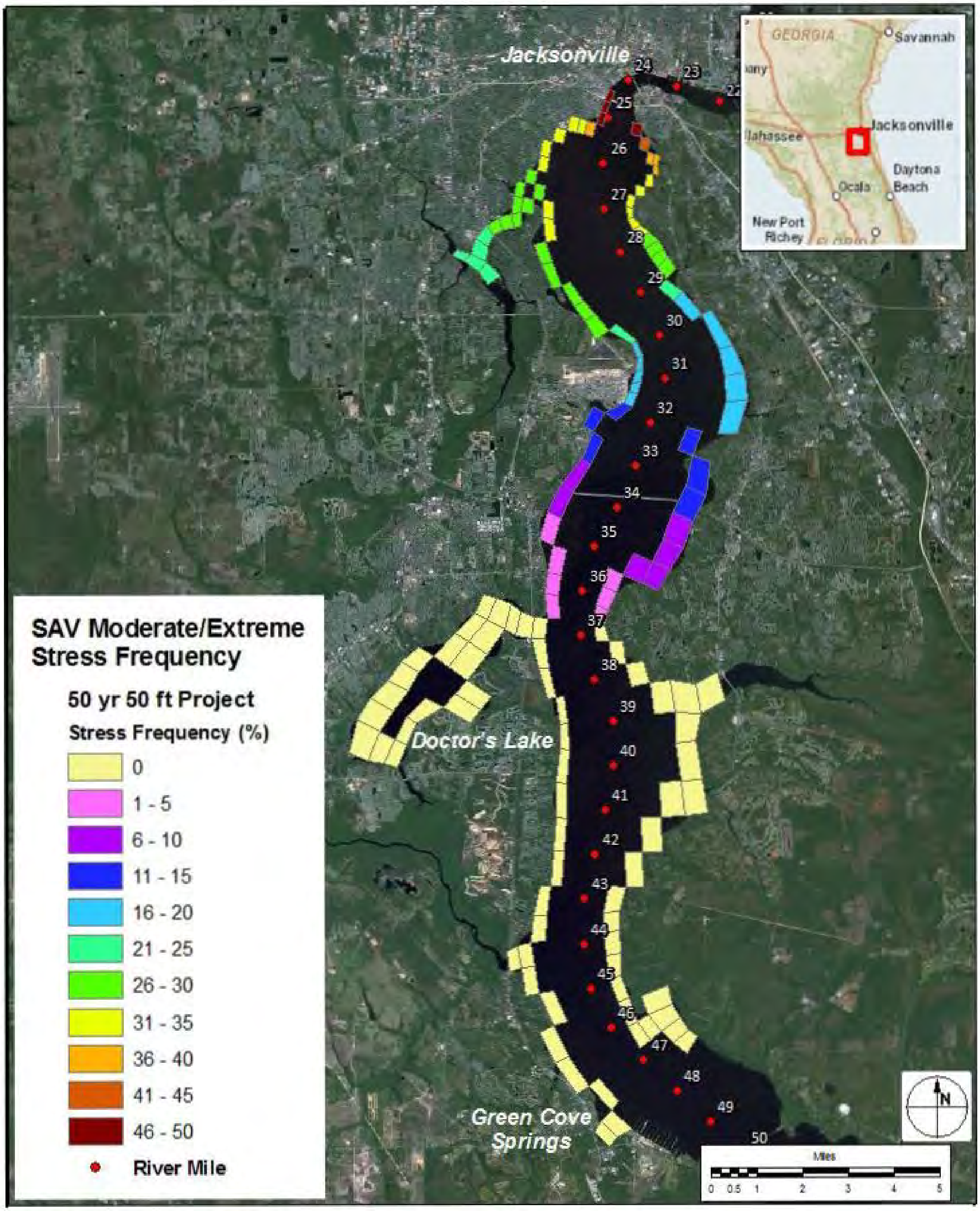

Figure 3.13 Frequency of Moderate/Extreme SAV Stress — 50-yr, 50-ft Project

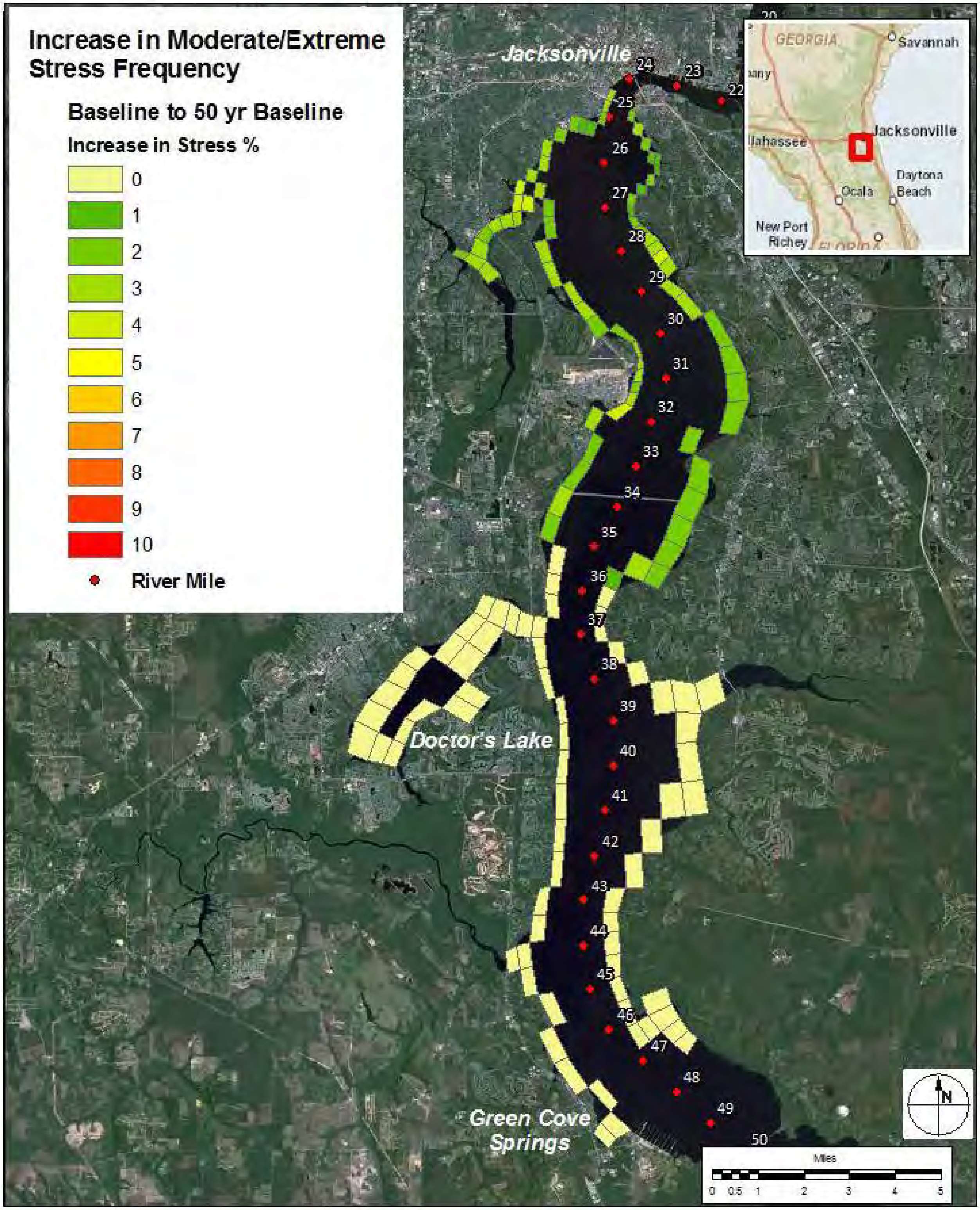

Figure 3.14 Increase in Moderate/Extreme SAV Stress — Baseline to 50-yr Baseline

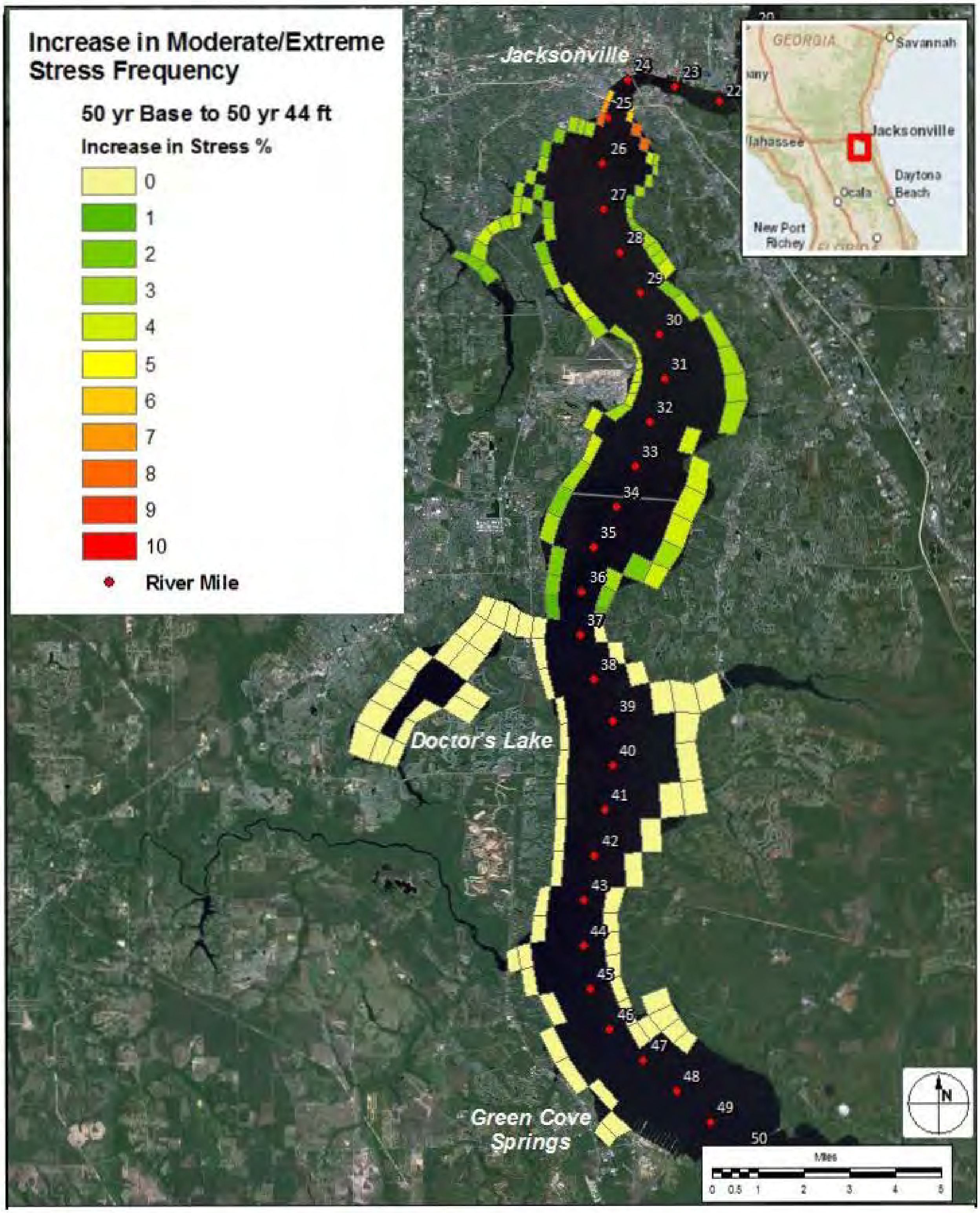

Figure 3.15 Increase in Moderate/Extreme SAV Stress — 50-yr Baseline to 50-yr, 44-ft Project

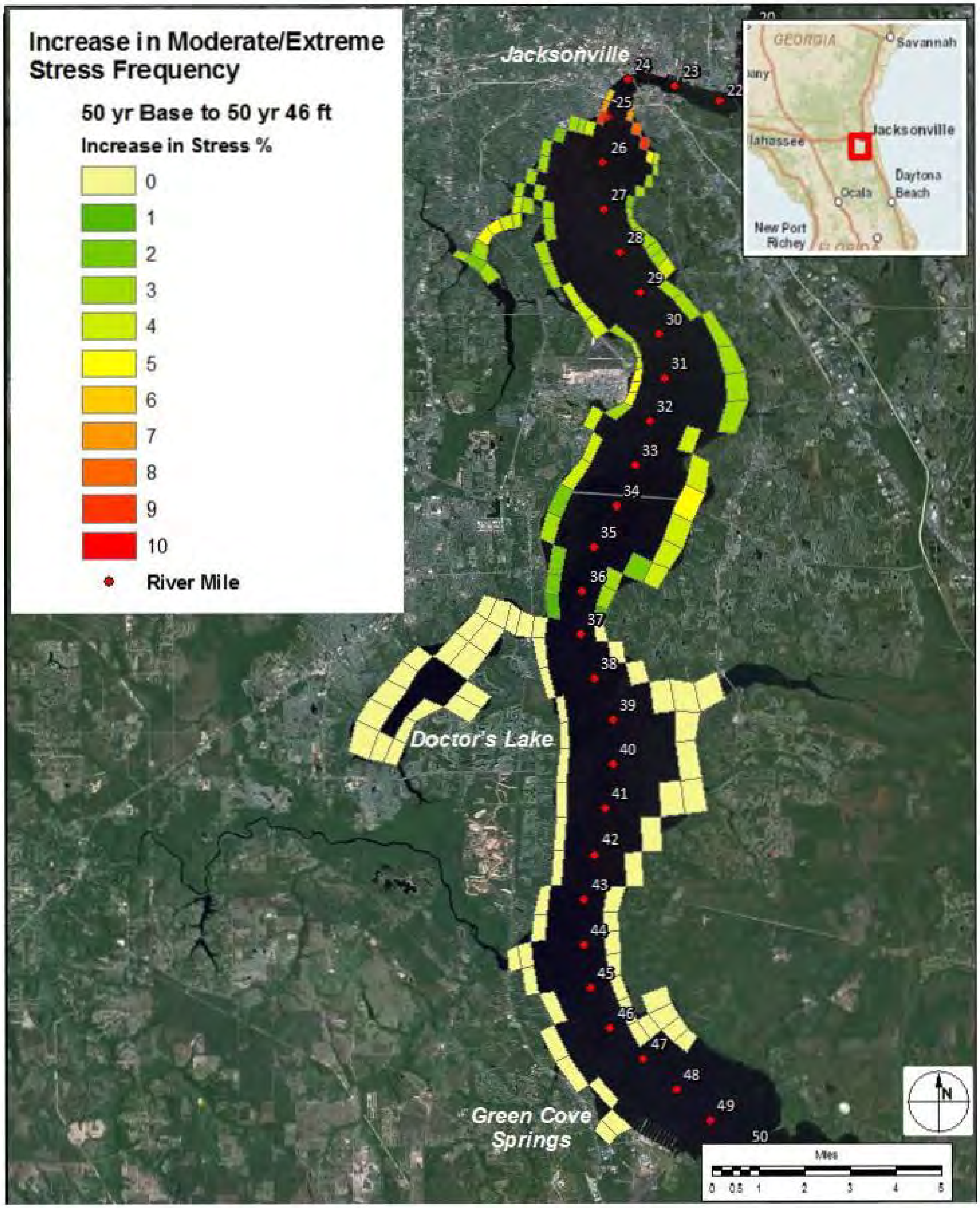

Figure 3.16 Increase in Moderate/Extreme SAV Stress — 50-yr Baseline to 50-yr, 46-ft Project

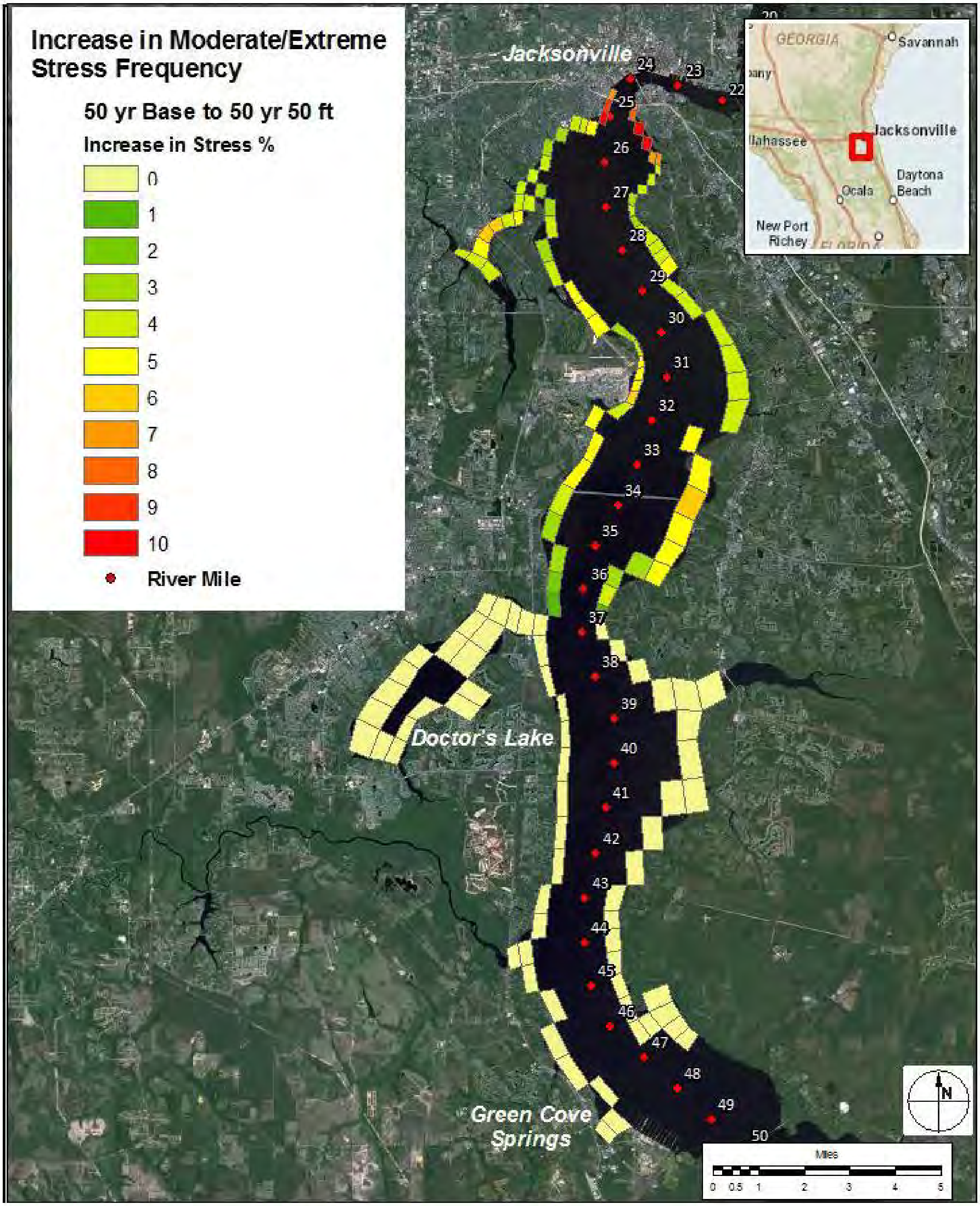

Figure 3.17 Increase in Moderate/Extreme SAV Stress — 50-yr Baseline to 50-yr, 50-ft Project

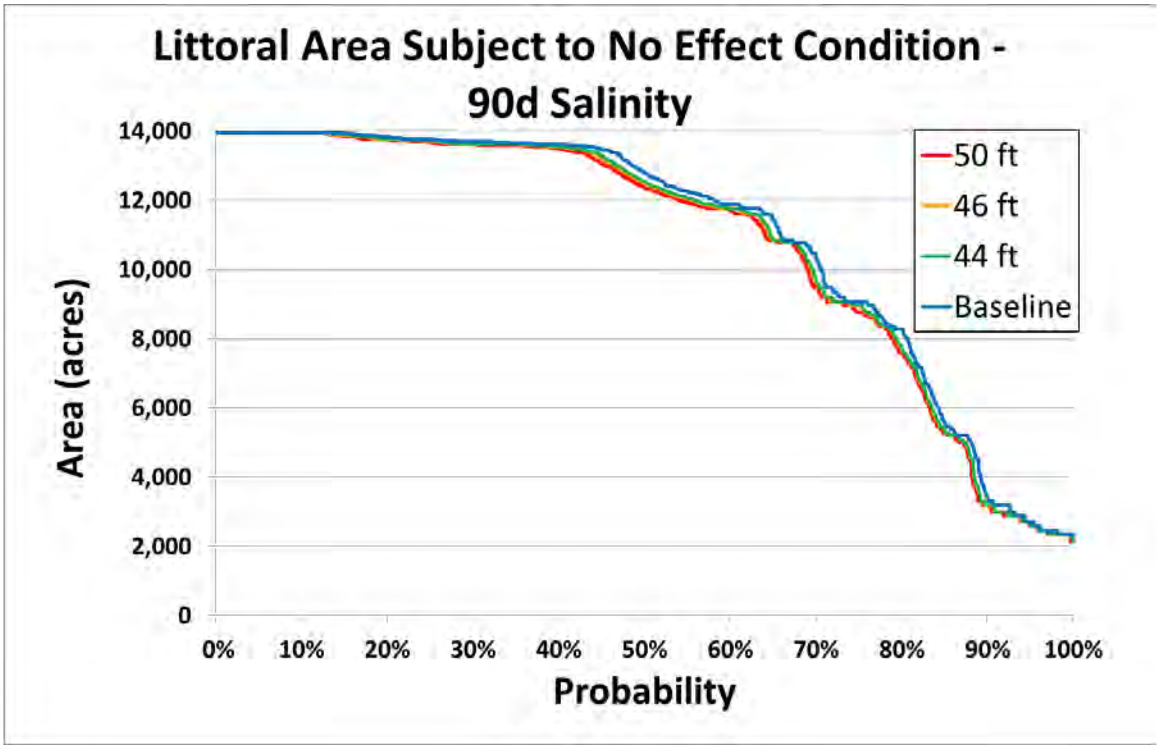

Figure 3.18 Littoral Area Subject To No Stress Effect

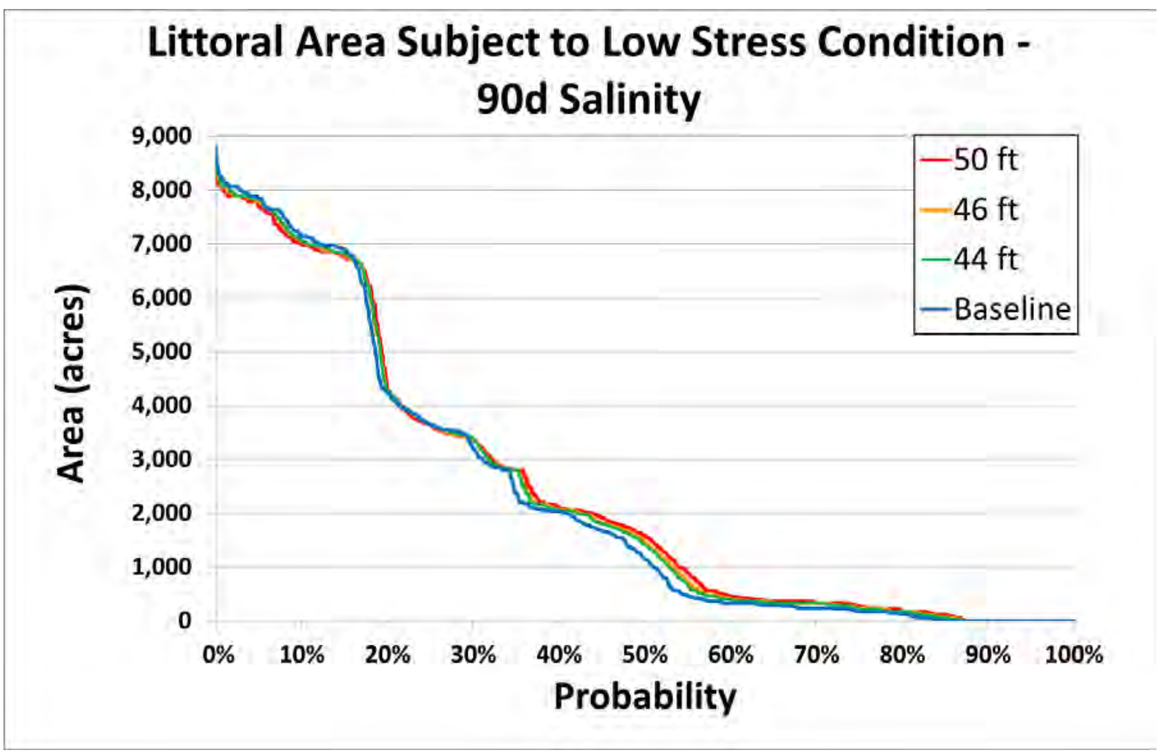

Figure 3.19 Littoral Area Subject To Low Stress Condition

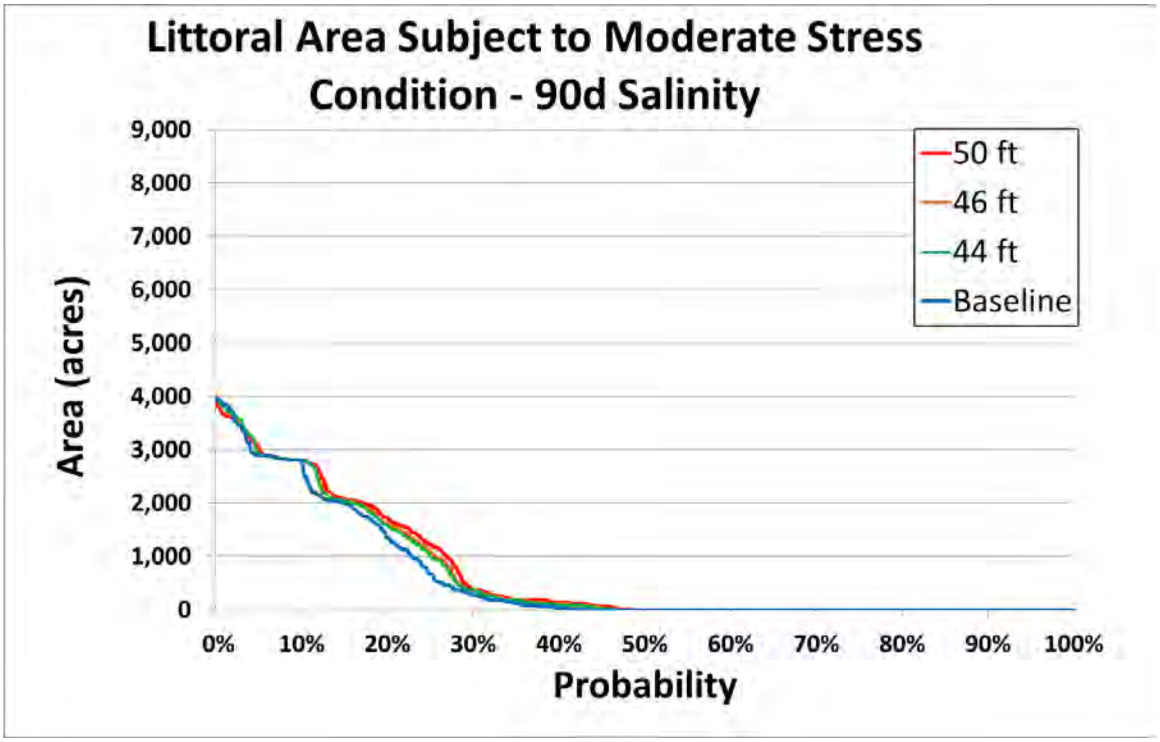

Figure 3.20 Littoral Area Subject To Moderate Stress Condition

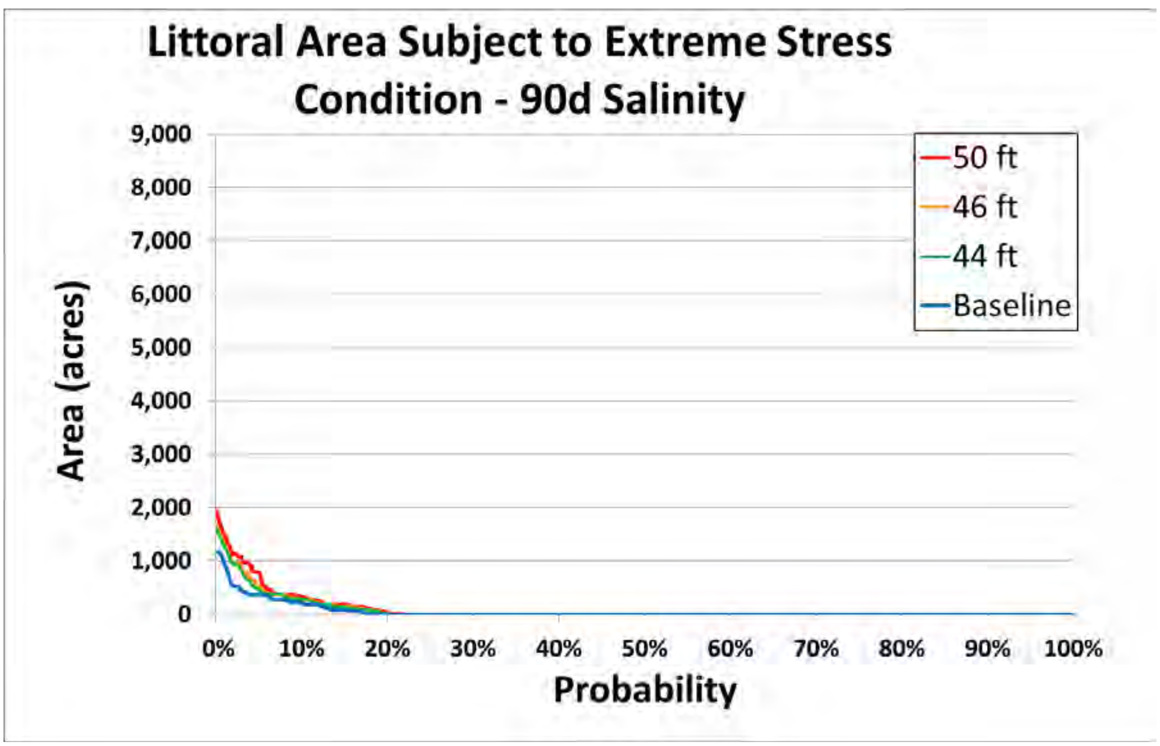

Figure 3.21 Littoral Area Subject To Extreme Stress Condition

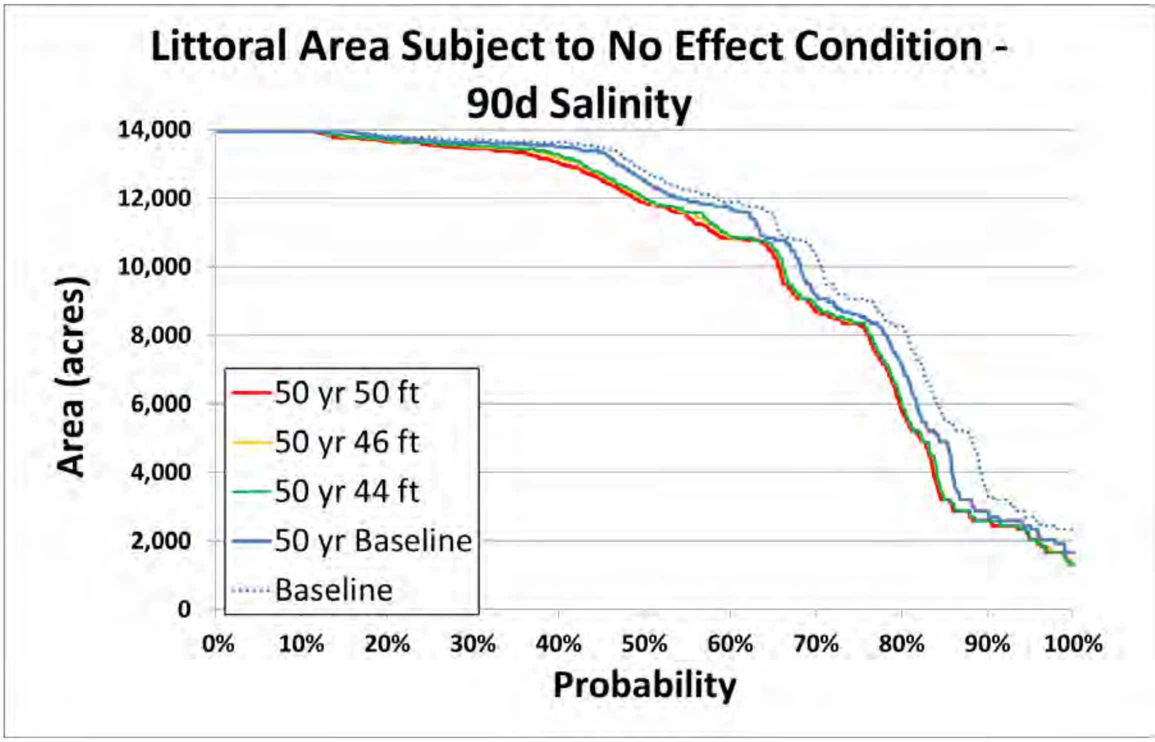

Figure 3.22 Littoral Area Subject To No Stress Effect At 50-yr Condition

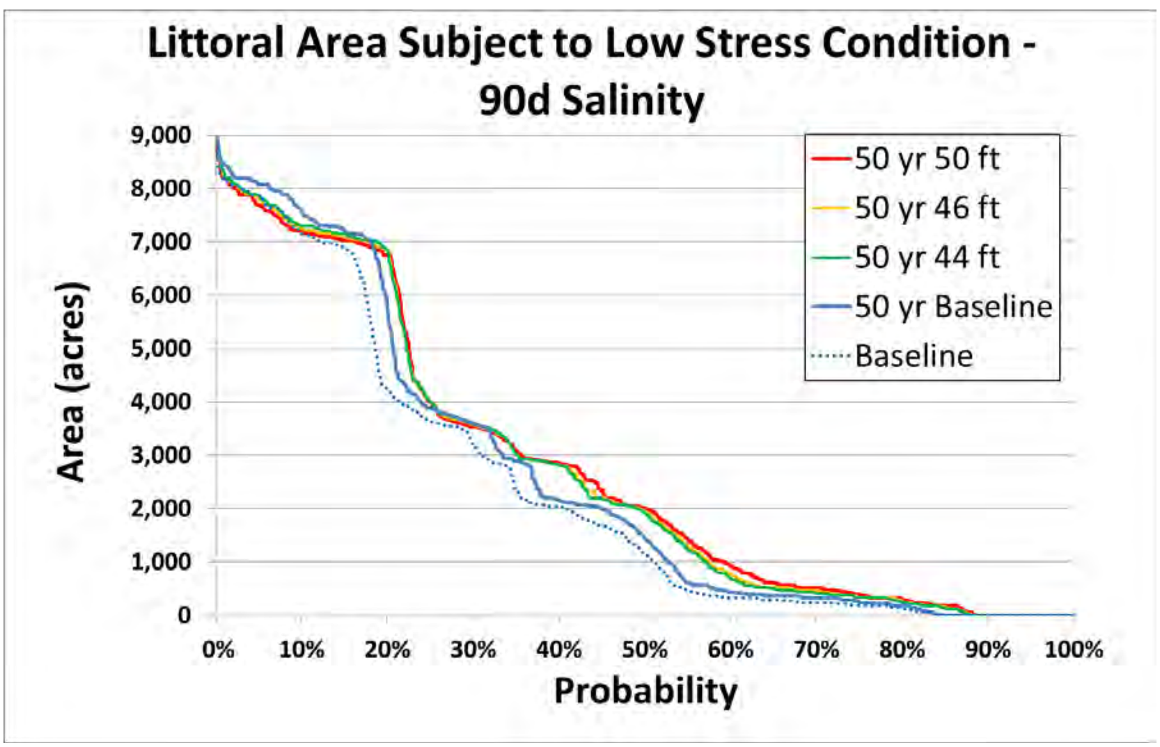

Figure 3.23 Littoral Area Subject To Low Stress At 50-yr Condition

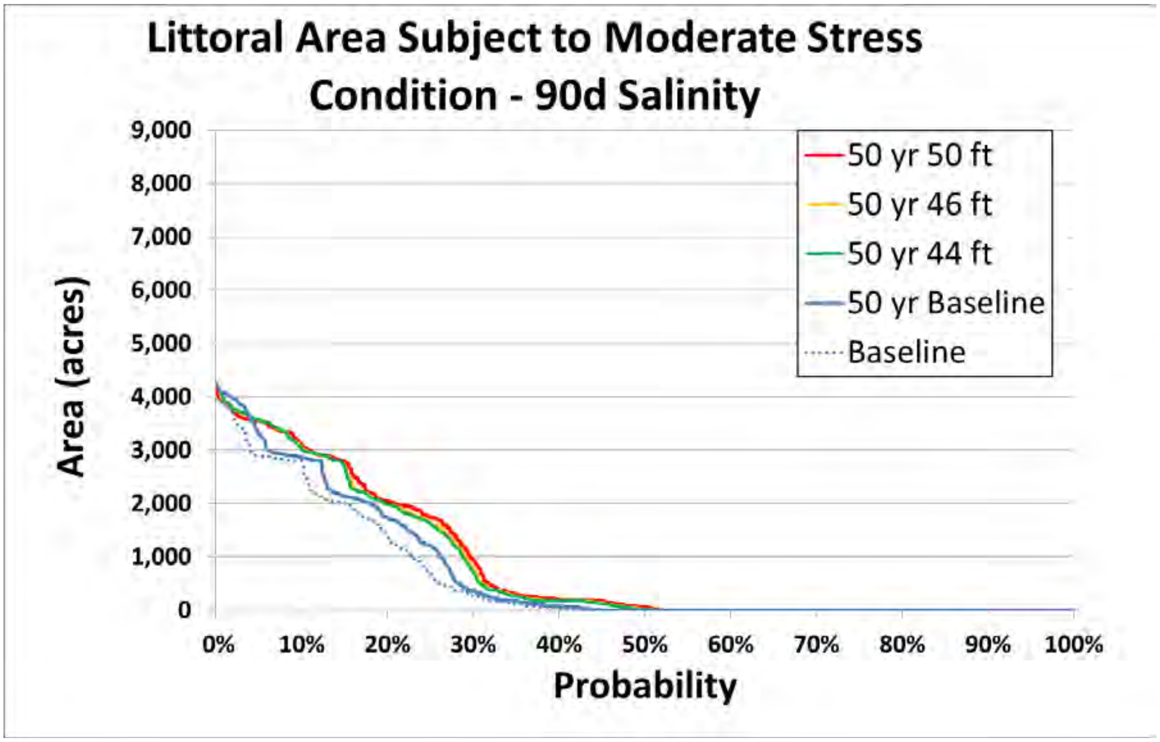

Figure 3.24 Littoral Area Subject To Moderate Stress At 50-yr Condition

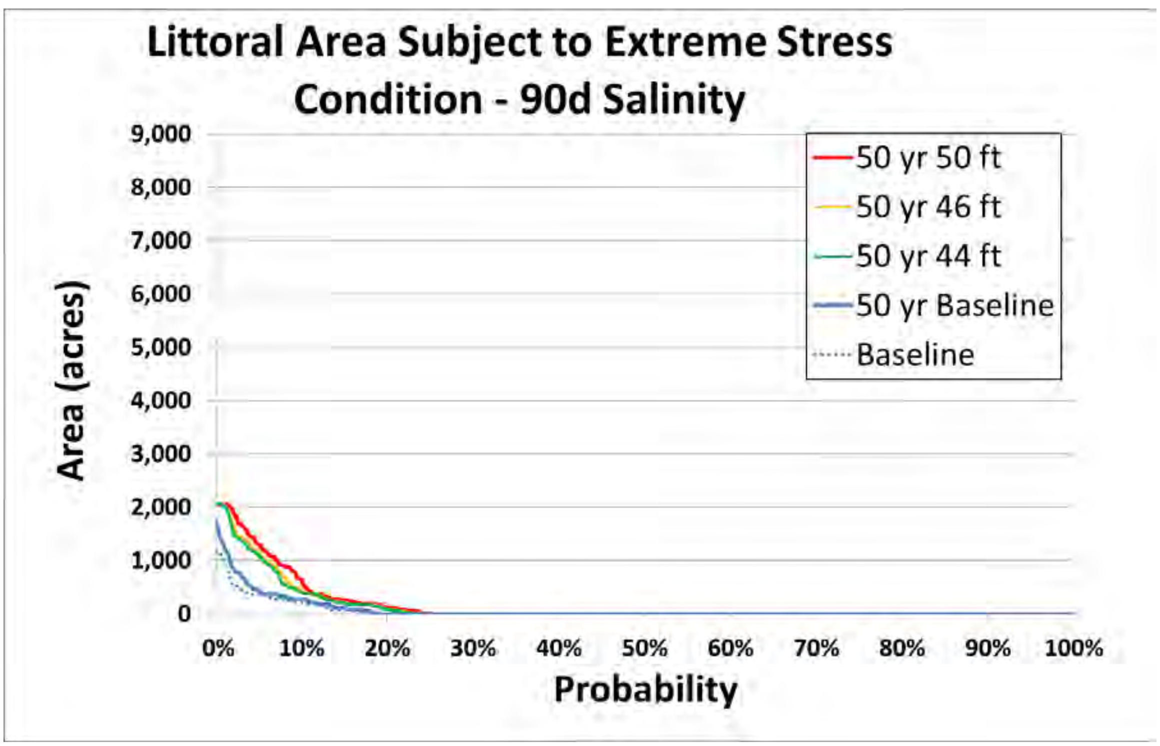

Figure 3.25 Littoral Area Subject To Extreme Stress At 50-yr Condition

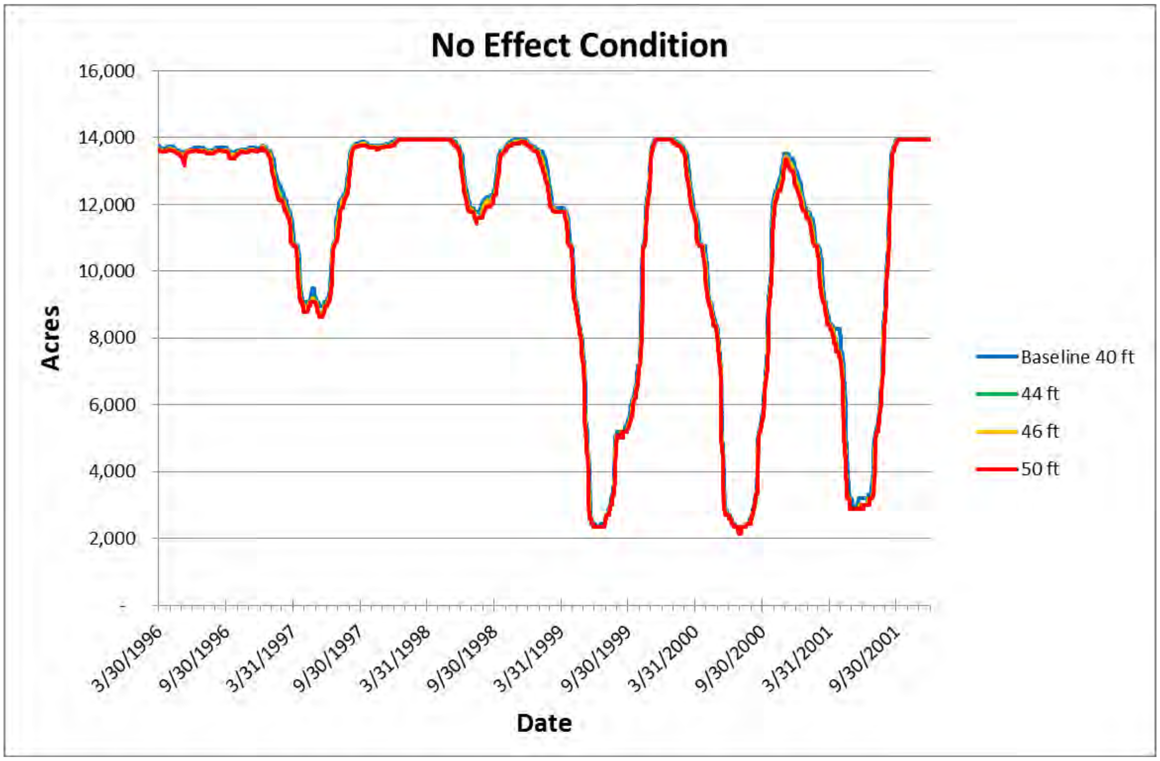

Figure 3.26 Temporal Distribution of No Stress Effect

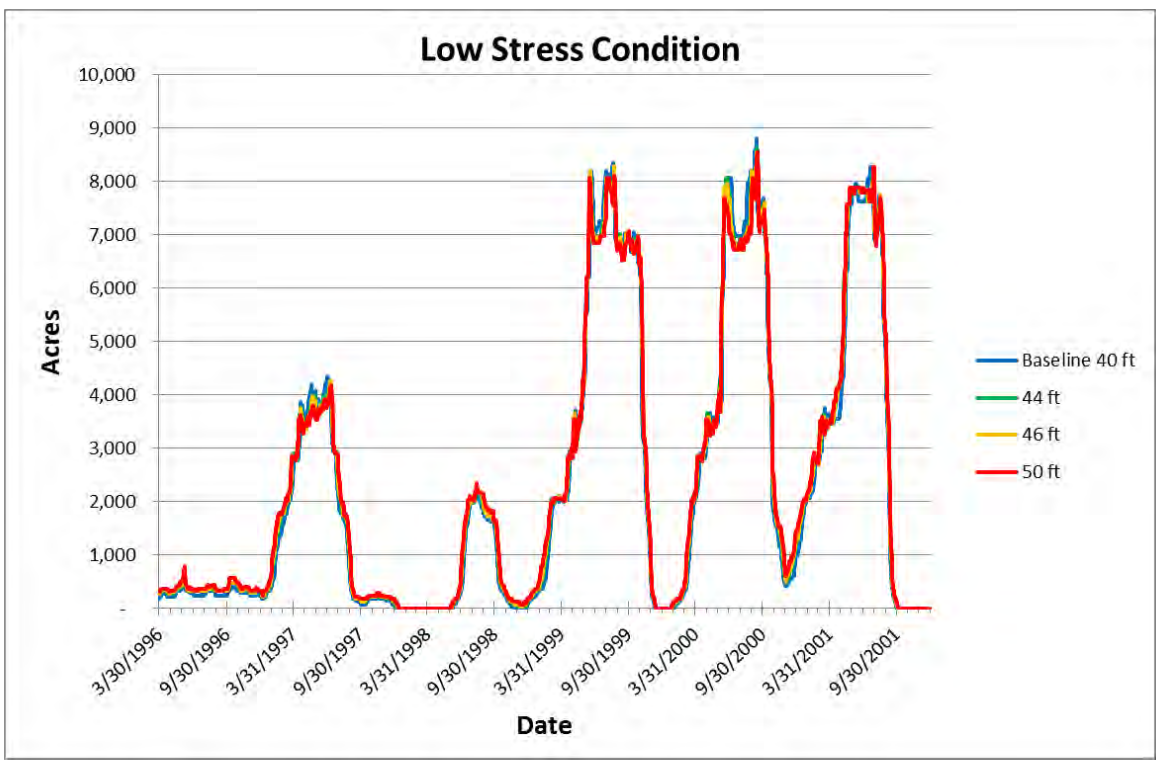

Figure 3.27 Temporal Distribution of Low Stress

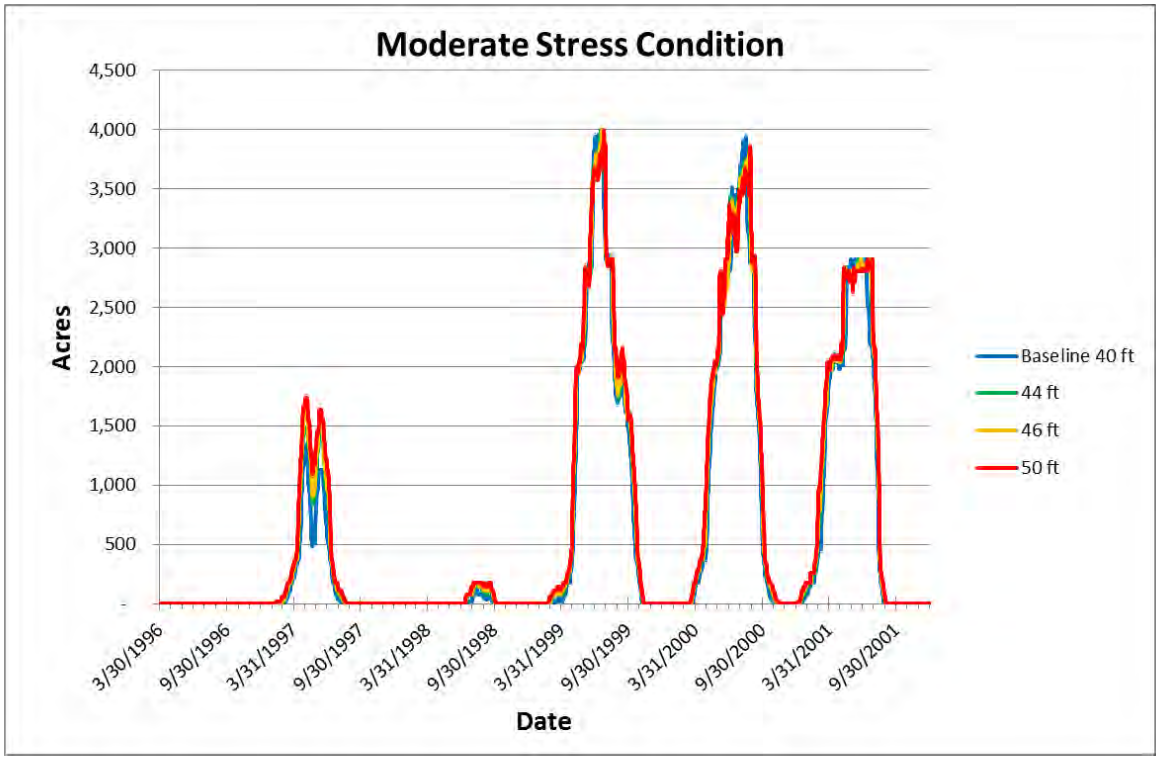

Figure 3.28 Temporal Distribution of Moderate Stress

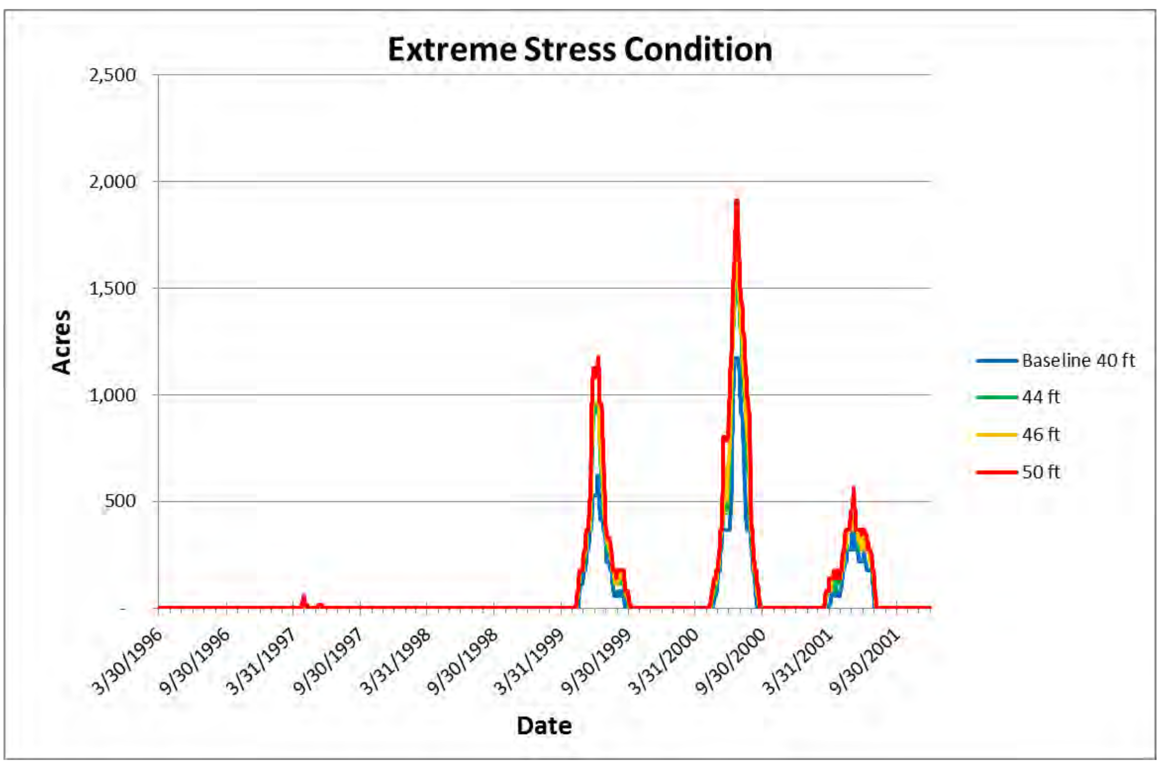

Figure 3.29 Temporal Distribution of Extreme Stress

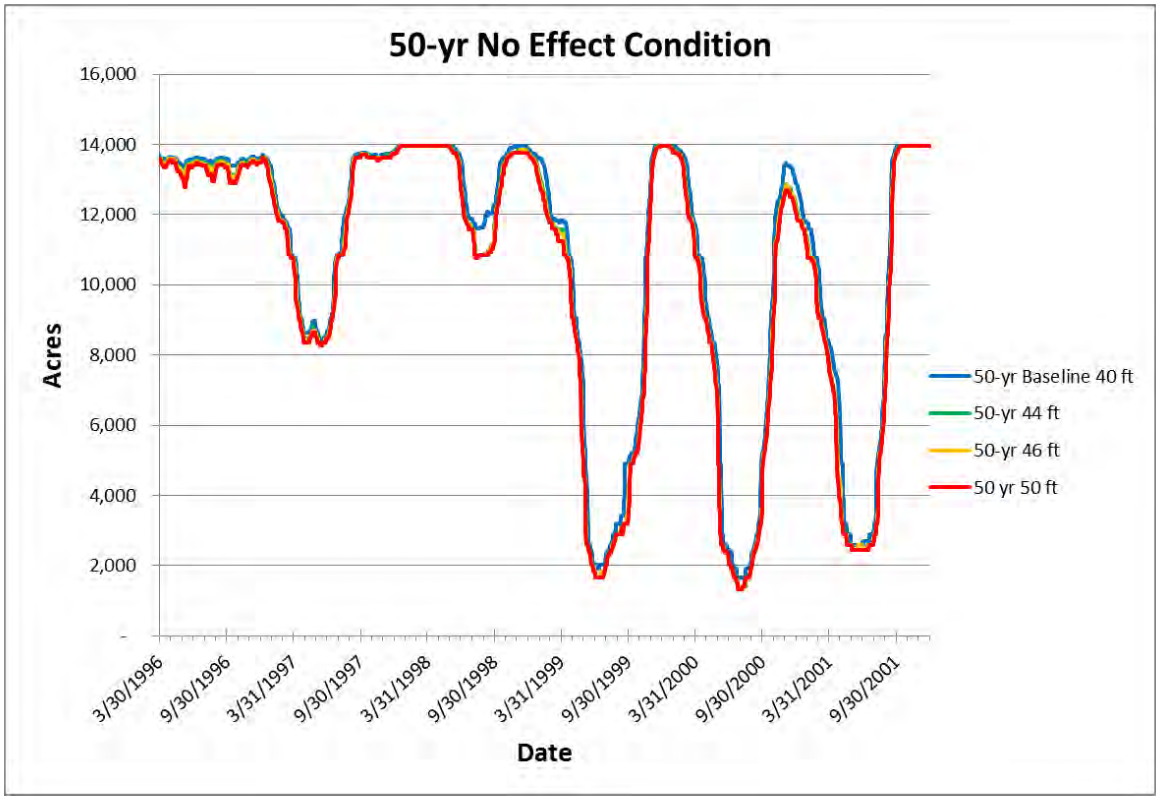

Figure 3.30 Temporal Distribution of No Stress Effect For 50-yr Condition

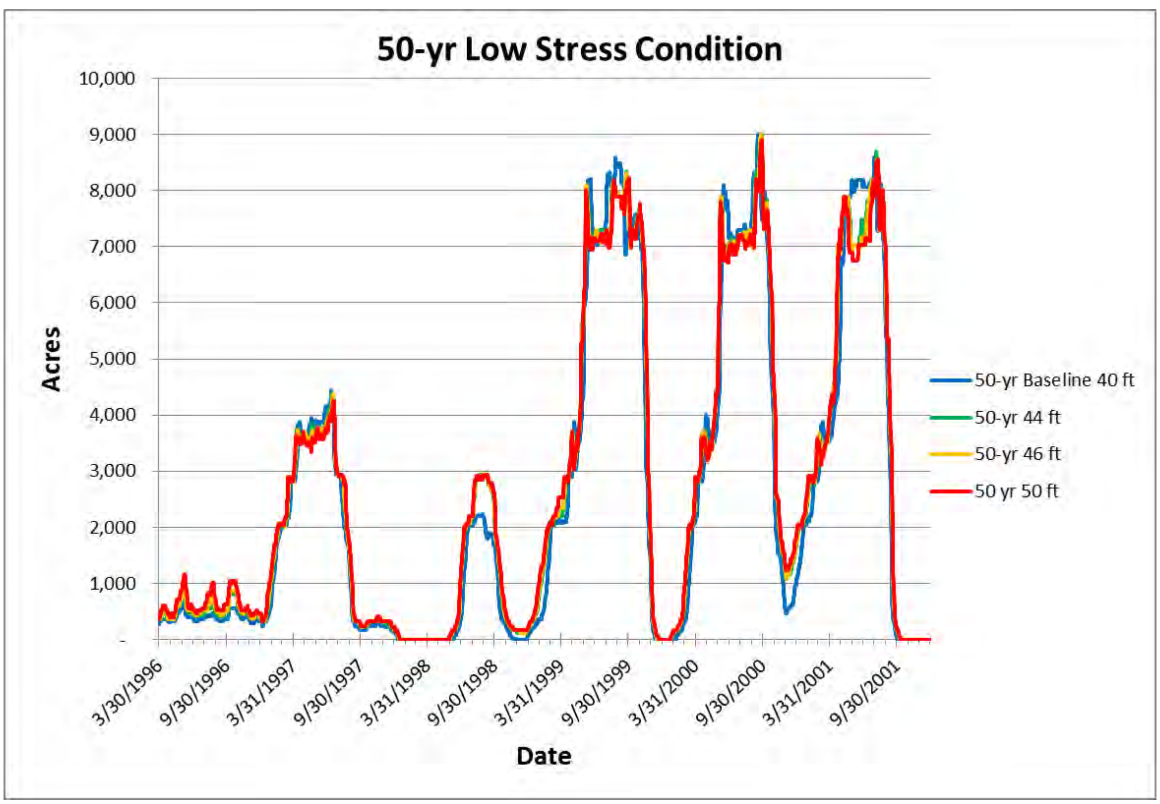

Figure 3.31 Temporal Distribution of Low Stress For 50-yr Condition

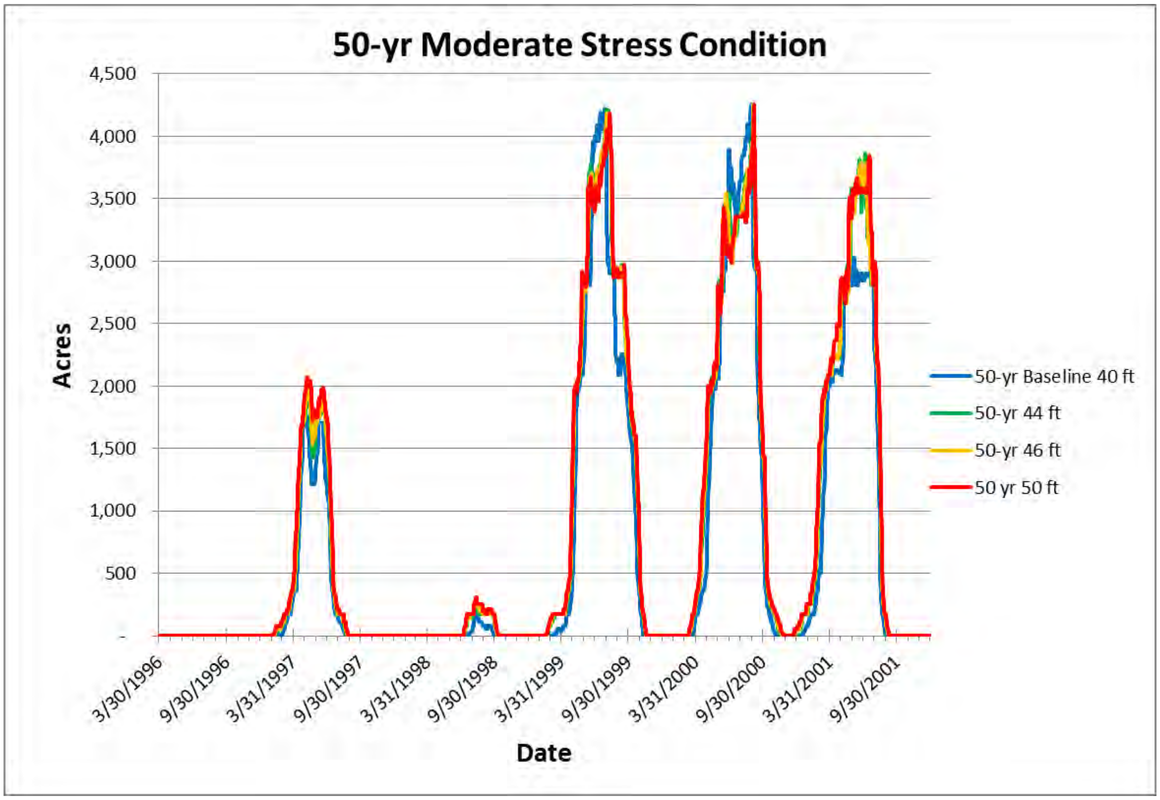

Figure 3.32 Temporal Distribution of Moderate Stress For 50-yr Condition

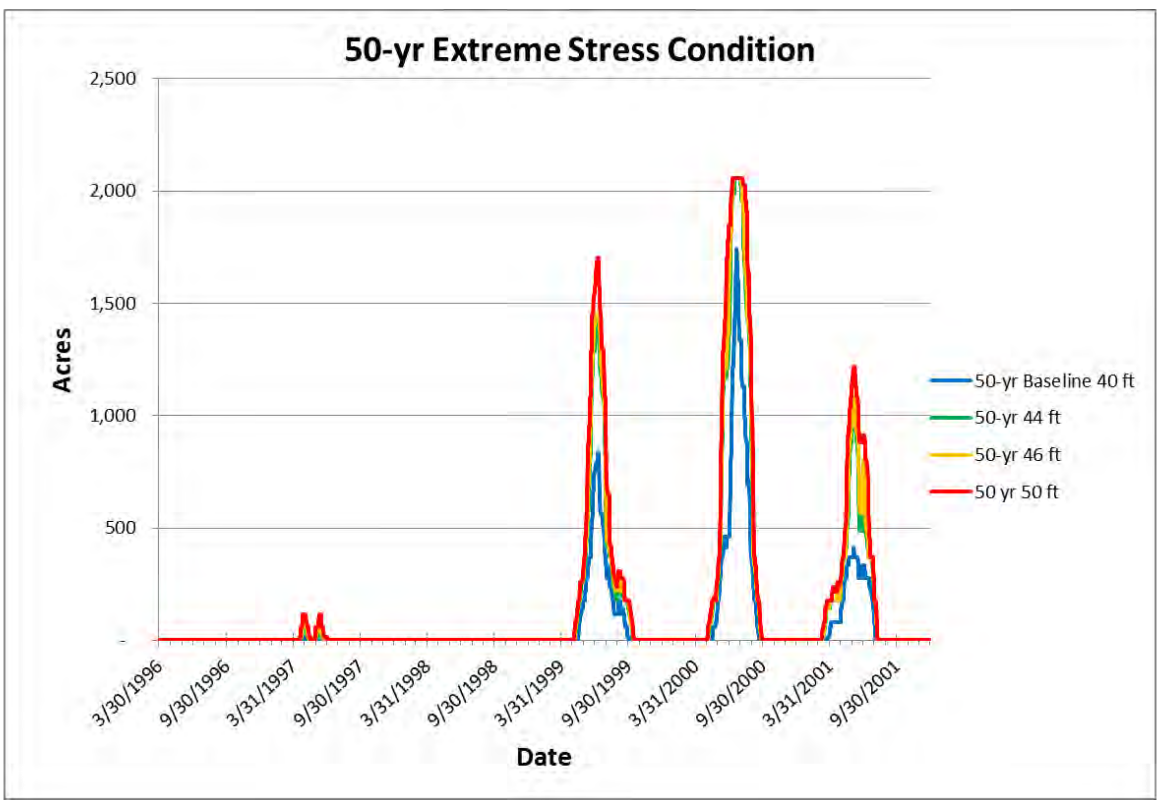

Figure 3.33 Temporal Distribution of Extreme Stress for 50-yr Condition

4.0 WETLANDS

Wetlands in the LSJR range from salt marsh in tidal, high salinity areas near the river mouth to freshwater marsh and swamps in upstream locations (Figure 4.1). In the Jacksonville Harbor Deepening GRR-2 study area (River Segments 1 – 3) salinity appears a major factor in determining wetland character. Some wetlands in these river segments appear in a state of transition from freshwater to brackish or saline conditions as evidenced by the appearance of salt tolerant vegetation in areas that were once freshwater swamp. In contrast, some areas in tributaries appear to have become fresher with increasing stormwater runoff (Kinser et al., 2012). On December 19, 2012 we conducted a limited field observation to note presence or absence of salt-tolerant vegetation at several locations along the river. We observed wetlands from readily accessible shorelines on both sides of the river from about a mile south of the Fuller Warren Bridge (river mile 26) to the Shands Bridge (river mile 50), including several points along the Ortega River. Consistent with SJRWMD land use data which indicate salt marsh wetlands south of the Fuller Warren Bridge (Figure 4.1), we observed salt marsh on both sides of the river from vantage points somewhat upstream of the bridge. The abundance of salt-tolerant vegetation and evidence of saline influence on the wetlands decreased upstream. We noted the presence of salt-tolerant vegetation or evidence of saline influence as far south as Black Creek near river mile 44. We saw no evidence of saline influence in wetlands near the Shands Bridge.

The proposed Jacksonville Harbor deepening will alter salinity distribution in the LSJR and thus may affect the distribution of salt tolerant wetland vegetation. Wetland distribution in the LSJR may also be influenced by water elevation which fluctuates in response to daily tidal changes, rainfall and freshwater inflow, and winds. The Jacksonville Harbor deepening will, however, have negligible effect on water elevation. This report therefore focuses on the effects of salinity changes on LSJR wetlands.

We assessed two approaches for evaluation of salinity-induced changes in wetlands due to Jacksonville Harbor deepening. Both approaches were based on salinity distribution simulated by the EFDC models of the baseline and project alternative conditions. The first approach was based on the SJRWMD WSIS wetlands model as described by Kinser et al. (2012). The second was based on recently analyzed results of wetland monitoring following channel deepening in the Cape Fear River and estuary (Hackney, 2013). A wetland effects model based on the Cape Fear monitoring data appeared to best describe potential effects of salinity increases on wetlands in the LSJR.

4.1 Wetlands Model

Following deepening of the Cape Fear River channel, Hackney (2013) monitored wetland vegetation, salinity, pore water sulfate, and other parameters at riverine and estuarine sampling stations. Monitoring occurred over a ten-year period at a series of sites influenced by a variety of salinity and flooding regimes. The monitoring data suggested that wetland transition from tidal swamp to tidal marsh was caused by increasing sulfate in the soil as a result of inundation with sulfate-laden saline water. Hackney found that the frequency of occurrence of high tide salinity exceeding 1.0 ppt predicted the saline condition that resulted in wetland transition. Cape Fear tidal swamps occurred where less than 12% of high tides resulted in >1 ppt salinity. Tidal marsh "dominated by species of herbaceous vascular plants with varying tolerance to saline water" occurred where more than 25% of high tides exceeded 1 ppt salinity. Where high tide inundation with >1ppt salinity occurred between 12% and 25% of the time, wetlands appeared in transition from tidal swamp to tidal marsh. Within this transition area freshwater vegetation exhibited indicators of salt-stress and salt intolerant vegetation disappeared from the wetlands. Based on the results of the LSJR salinity models and field observations of tidal wetland vegetation in the LSJR, the tidal swamp to tidal marsh transition in the LSJR appears to follow a pattern similar to that documented in the Cape Fear River (Hackney, C.T., 2013, personal communication).

Based on locations of wetlands mapped according to the Florida Land Use, Cover, and Forms Classification System (FLUCCS) codes in the SJRWMD 2009 land use GIS data set, wetlands along the LSJR downstream of the Fuller Warren Bridge (river mile 24.5) are predominately salt marsh (Figure 4.1). Any project-induced salinity changes in this section of the river are unlikely to affect those salt marsh wetlands. We therefore set the downstream limit for wetlands evaluation at the Fuller Warren Bridge. The EFDC simulation results (Taylor, 2013) indicated that the deepest project alternative would cause little or no change in salinity upstream of the Shands Bridge (river mile 50). However, the model also showed that salinity greater than 1 ppt would occur at the Shands Bridge, so we set the upstream boundary for wetland evaluation farther upriver at Federal Point (river mile 64).

The littoral cells in the EFDC model grid represent the water that would inundate wetlands adjacent to the river. For each of those littoral cells between the Fuller Warren Bridge and Federal Point, we extracted salinity at each high tide during the six-year simulation period. This resulted in a data set of approximately 4,230 high tide records for each cell. We then calculated the frequency of occurrence of high tide salinity >1 ppt for each cell. Figures showing the frequency of occurrence of >1ppt high tide salinity in each cell and the locations of the 12% and 25% frequencies allowed comparison of the simulated project alternatives to the no action condition.

4.2 Application of the Wetlands Model for Jacksonville Harbor Deepening GRR-2 Ecological Effects Evaluation

Hydrodynamic model simulation of the No Action Alternative post-project condition indicated that high tide salinity greater than 1 ppt occurs at 12% or less frequency south of the Shands Bridge (river mile 50) (Figure 4.2). The wetland model suggests that wetlands south of that point should be tidal swamp communities, with little or no evidence of saline influence. High tide salinity >1 ppt occurs at 25% or greater frequency north of Black Creek (river mile 44.5). The wetland model indicates that these areas should be saline influenced tidal marsh. The No Action Alternative model results indicate a tidal swamp to tidal marsh wetland transition zone about 5.5 miles long between Black Creek and the Shands Bridge. The modeled results are consistent with field observations which found evidence of saline influence in wetlands as far south as Black Creek. Evidence of saline influence in the wetlands disappeared between Black Creek and the Shands Bridge.

For the 44-ft project alternative, the location of the <12% frequency of 1 ppt high tide salinity does not differ from the No Action Alternative. The location of the >25% frequency of 1 ppt high tide salinity moves about 0.5 mile upstream on the east side of the river relative its location for the No Action Alternative (Figure 4.3). The overall effect of the 44-ft project alternative is to shorten the tidal swamp to tidal marsh transition area by about 0.5 miles on the east side of the river. Freshwater inflow from Black Creek may prevent higher salinity water from moving farther upstream along the west side of the River.

Neither the 46-ft nor 50-ft project alternative >25% and <12% frequency of 1 ppt high tide locations differ from the 44-ft project alternative (Figures 4.4 and 4.5).

The model results indicate that the project alternatives will have little effect on the upstream location of the transition zone from tidal swamp to tidal marsh along the main stem of the LSJR. The downstream location will shift about 0.5 mile upstream on the east side of the river, but few wetland systems occur along the shoreline in that area. However, freshwater wetlands in Black Creek on the west side of the river and Hallowes Cove on the east side of the river are located in the northern part of the transition zone and could be affected by increased salinity during periods of extreme drought.

From the Fuller Warren Bridge upriver to the 25% frequency of >1ppt high tide salinity location, wetlands will remain influenced by saline water with the No Action Alternative. The project alternatives will cause increased salinity and increased frequency of high tide salinity >1 ppt in this area. An increased frequency of higher salinities could result in the loss of the most salt-sensitive vegetation, including hardwoods, and increased abundance of opportunistic salt tolerant vegetation. Sulfate introduced into the soils with saline water could shift soil microbial metabolism towards sulfate reduction. The alteration of metabolic pathways could increase organic matter degradation rates and lead to subsidence of the wetland soil surface. These changes could result in the upstream movement of salt marsh wetlands. The upstream distance of salt marsh cannot be reliably predicted.

The 50-yr post-project simulations (i.e., 2068 condition) include the effects of sea level rise and water withdrawal. The net effect of these factors is an upstream shift of salinity influence on wetlands for the No Action Alternative and any of the project alternatives. The 50-yr No Action Alternative simulation results indicate 12% frequency of occurrence of >1 ppt high tide salinity occurs at river mile 52, about 2 miles upstream of its post-project location (Figure 4.6). The 25% frequency of >1 ppt high tide salinity occurs at river mile 47, about 2.5 miles upstream of its post-project location. Based on the movement of this indicator, wetlands near the mouth of Black Creek may convert to saline influenced tidal marsh. Relative to the post-project condition, the upstream movement of the tidal swamp to tidal marsh transition zone potentially affects freshwater wetland systems between the Shands Bridge and Six-Mile Creek.

None of the 50-yr post-project alternative simulations indicated any shift in location of the 12% or 25% frequency >1 ppt high tide salinity locations relative to the 50-yr post-project No Action Alternative (Figures 4.7, 4.8, 4.9).

The above discussion deals with potential effects of salinity changes on wetlands occurring along the shoreline of the main stem of the LSJR. Salinity changes in the main stem would also influence salinity in tributaries. The EFDC model simulation did not extend into tributary streams to allow evaluation of salinity changes outside of the main stem of the river. However, the USACE intends to perform additional modeling of tributaries to provide information about salinity distribution in selected tributaries and marshes. The tributary model results, expected in late spring 2013, will be incorporated into the final version of this report.

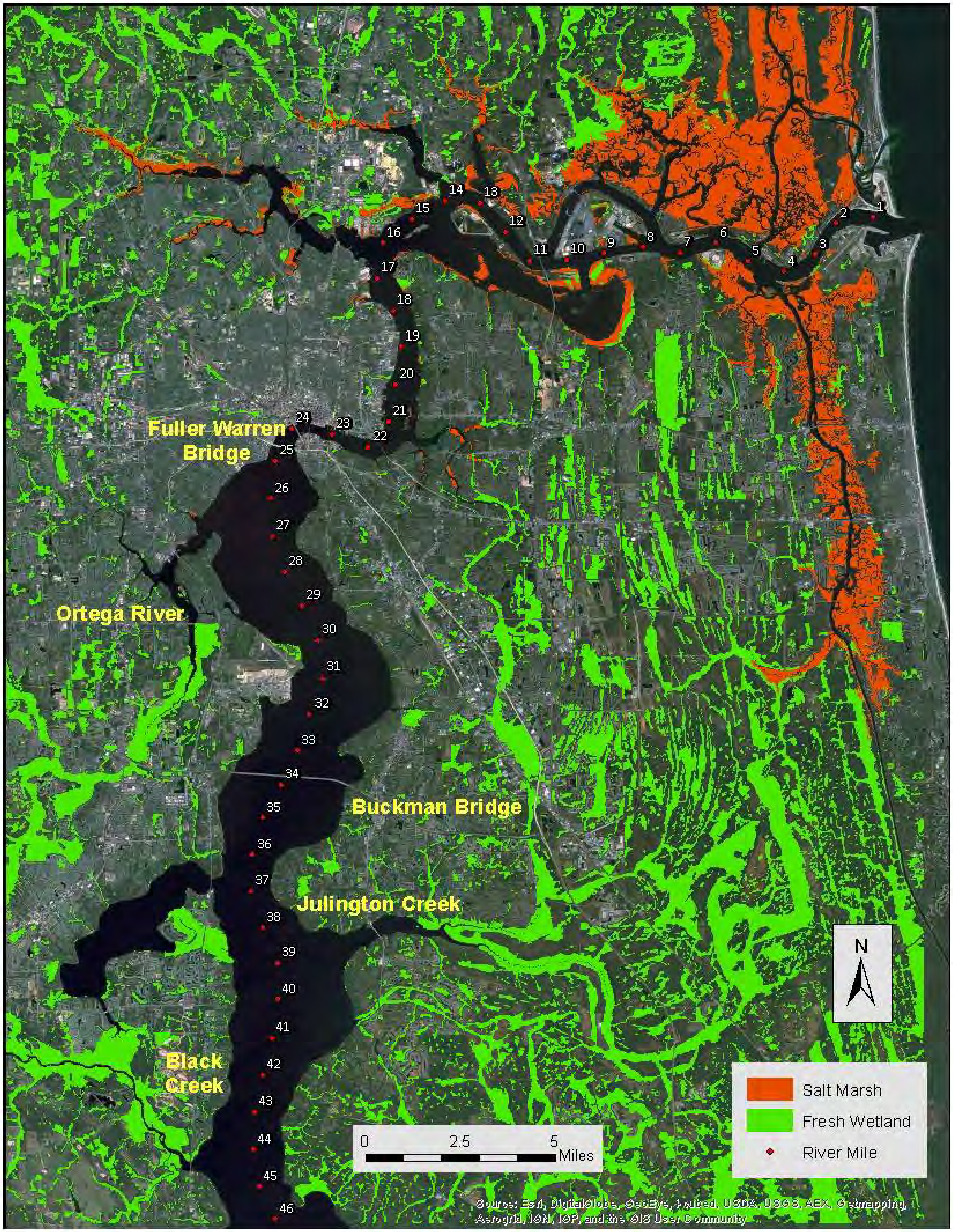

Figure 4.1 Wetland Distribution along the LSJR from Mouth to Black Creek.

Source: SJRWMD 2009 Land Use Data

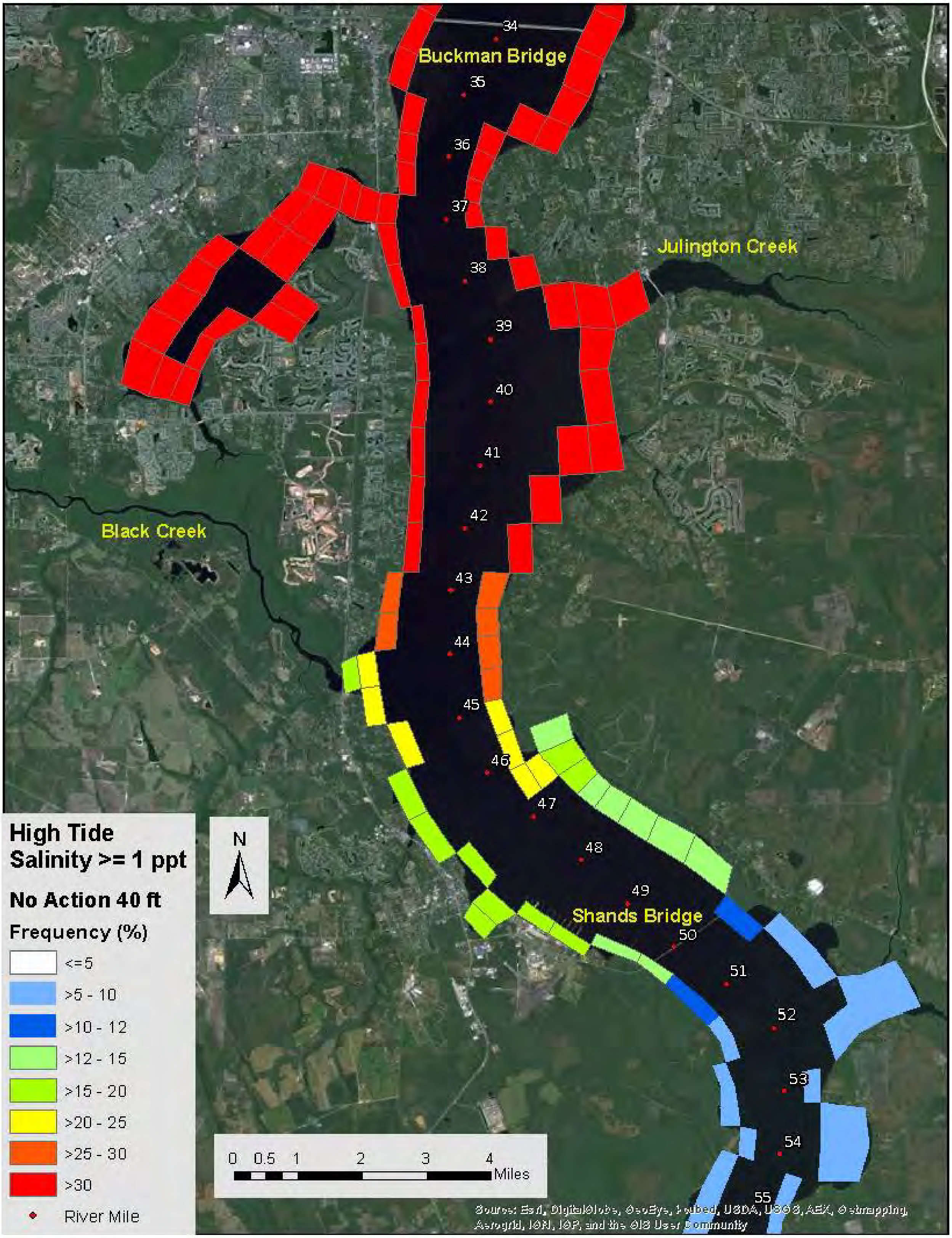

Figure 4.2 High tide >1 ppt Salinity Frequency, No-Action Alternative

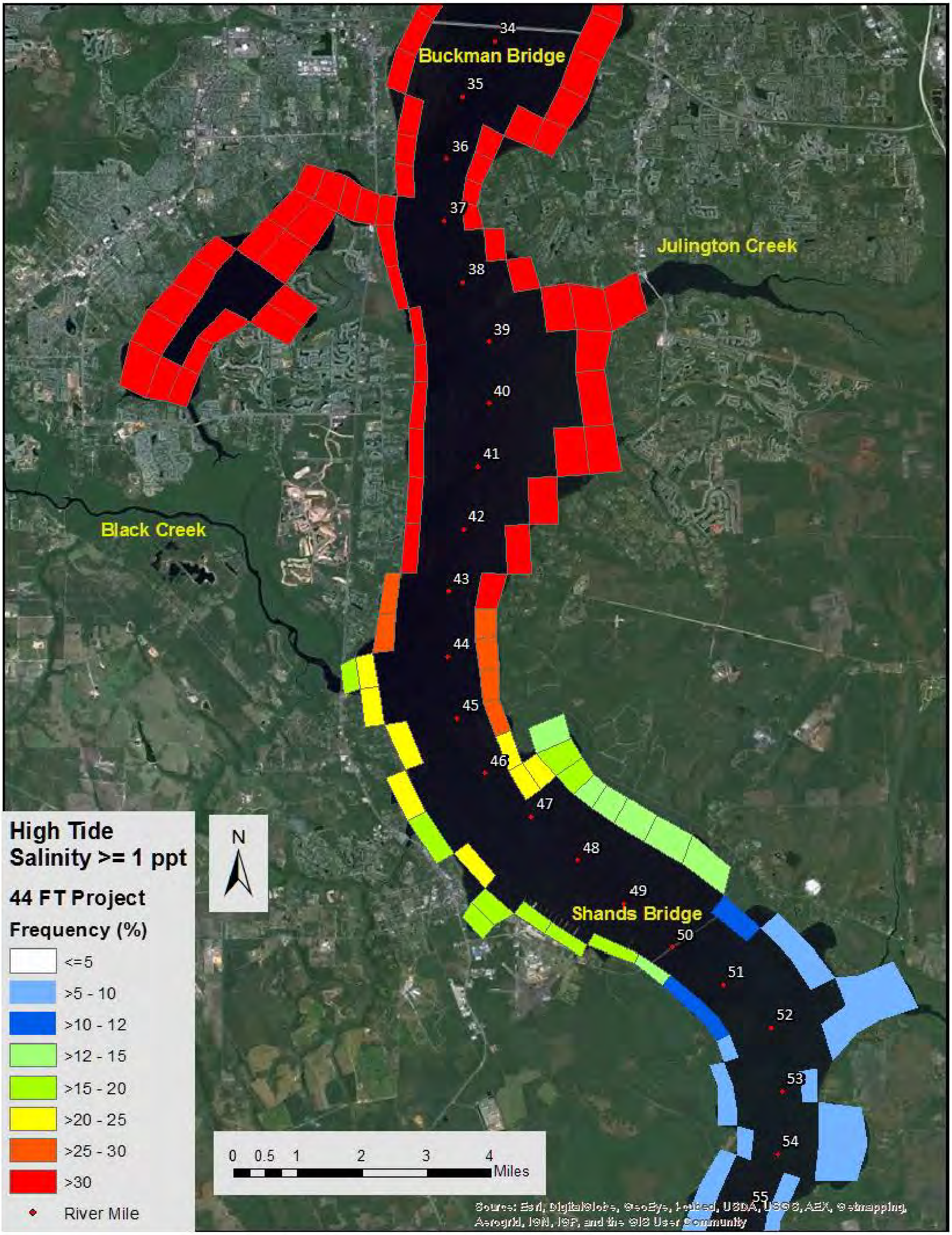

Figure 4.3 High tide >1 ppt Salinity Frequency, 44-Ft Project

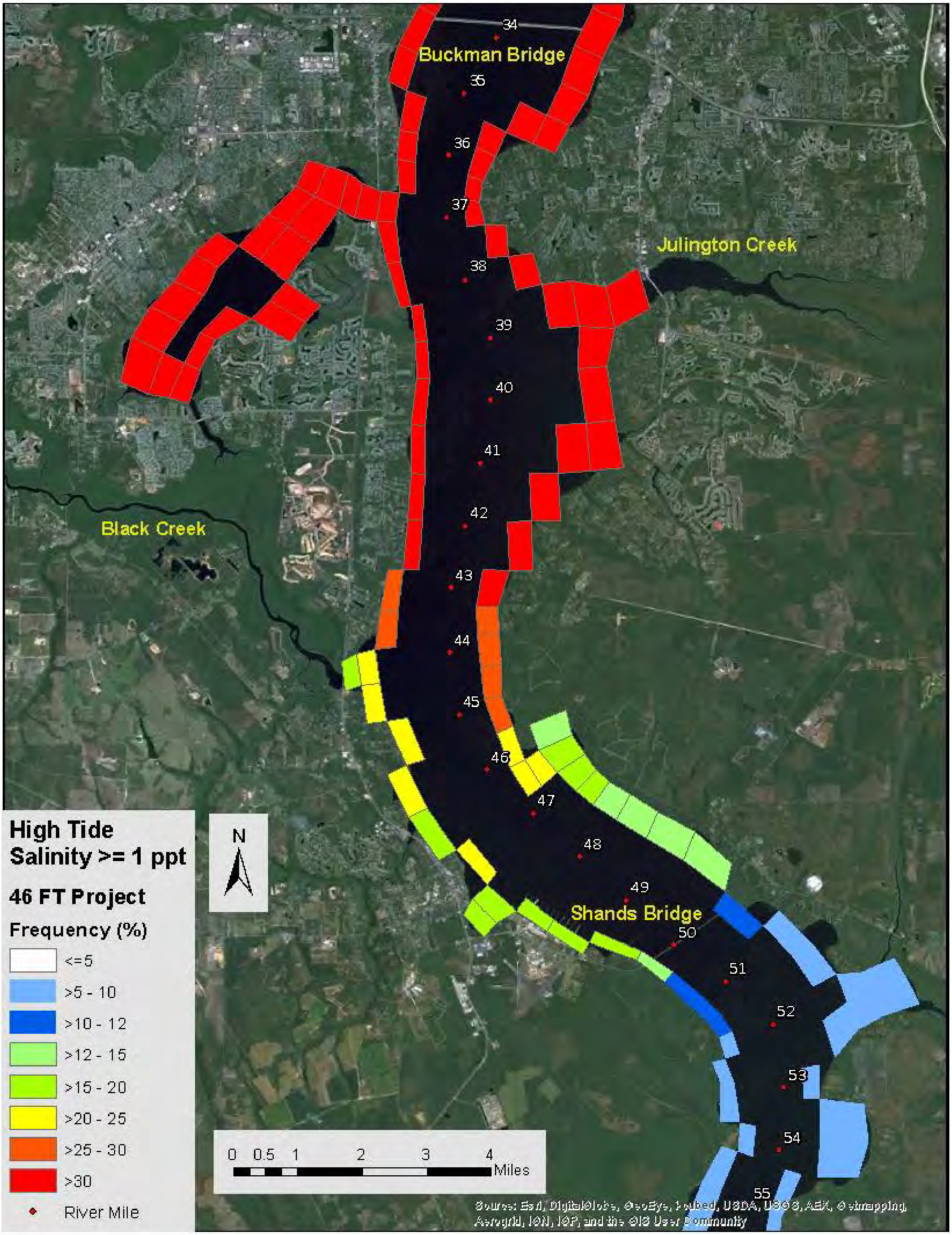

Figure 4.4 High tide >1 ppt Salinity Frequency, 46-Ft Project

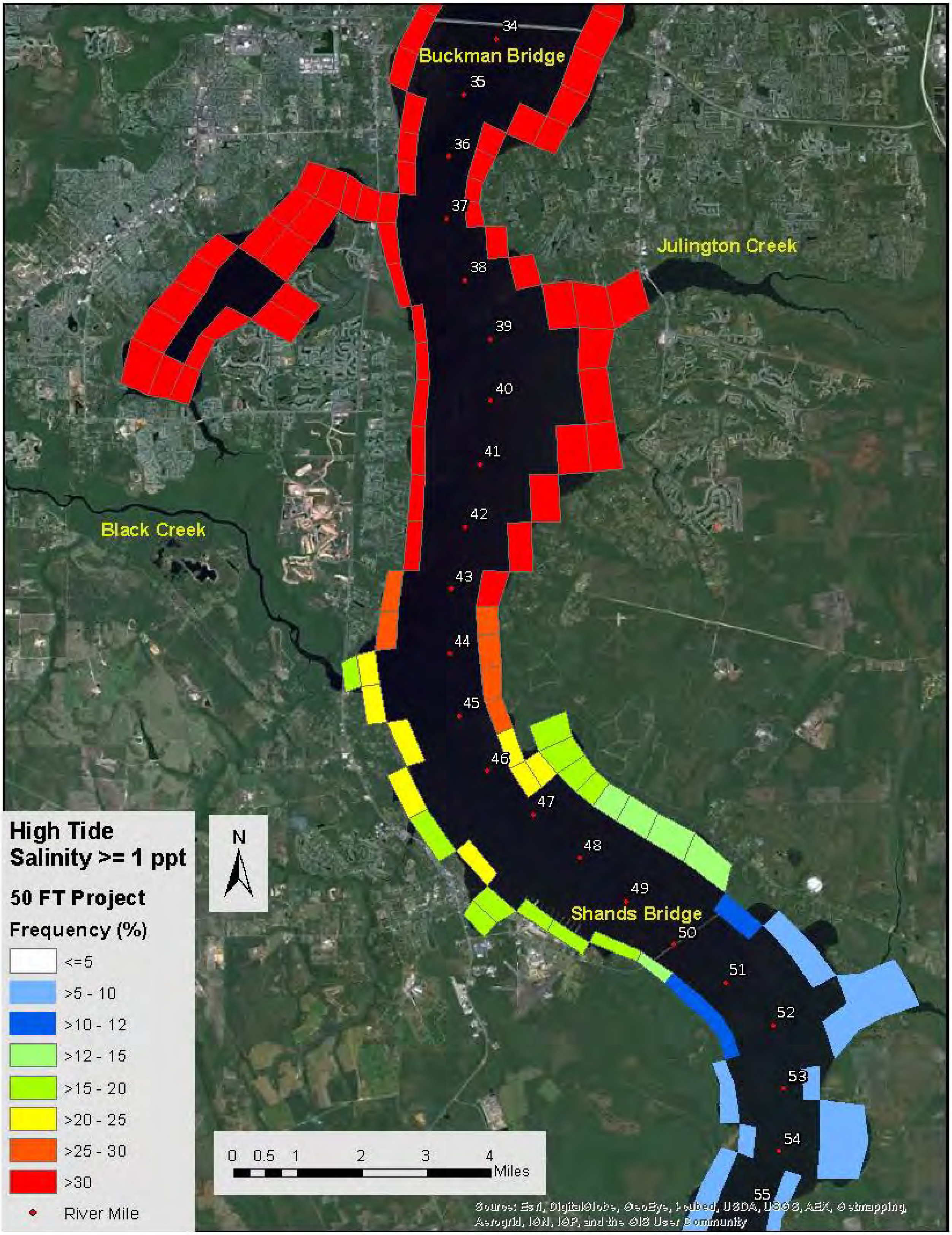

Figure 4.5 High tide >1 ppt Salinity Frequency, 50-Ft Project

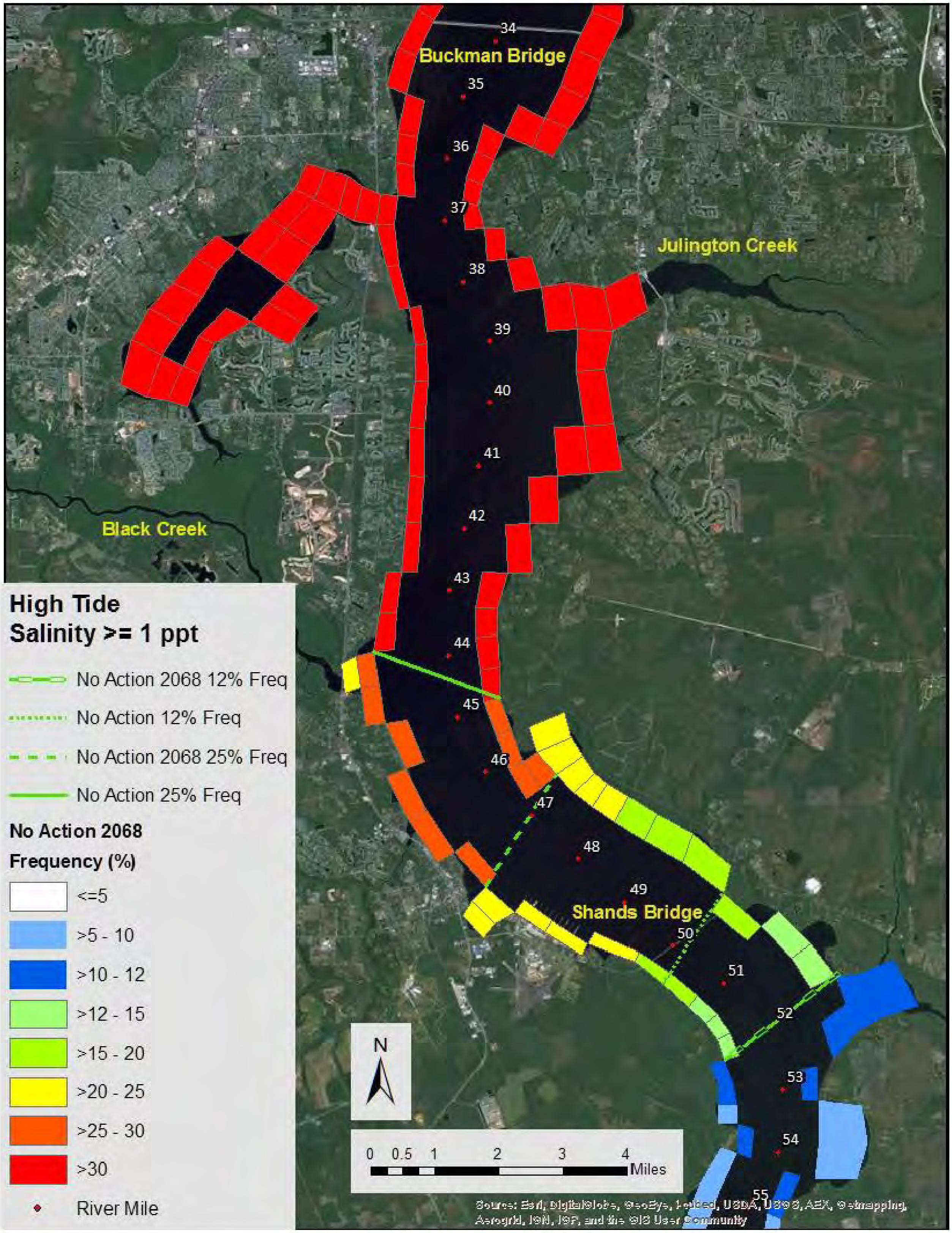

Figure 4.6 High tide >1 ppt Salinity Frequency, 50-Yr No-Action Alternative

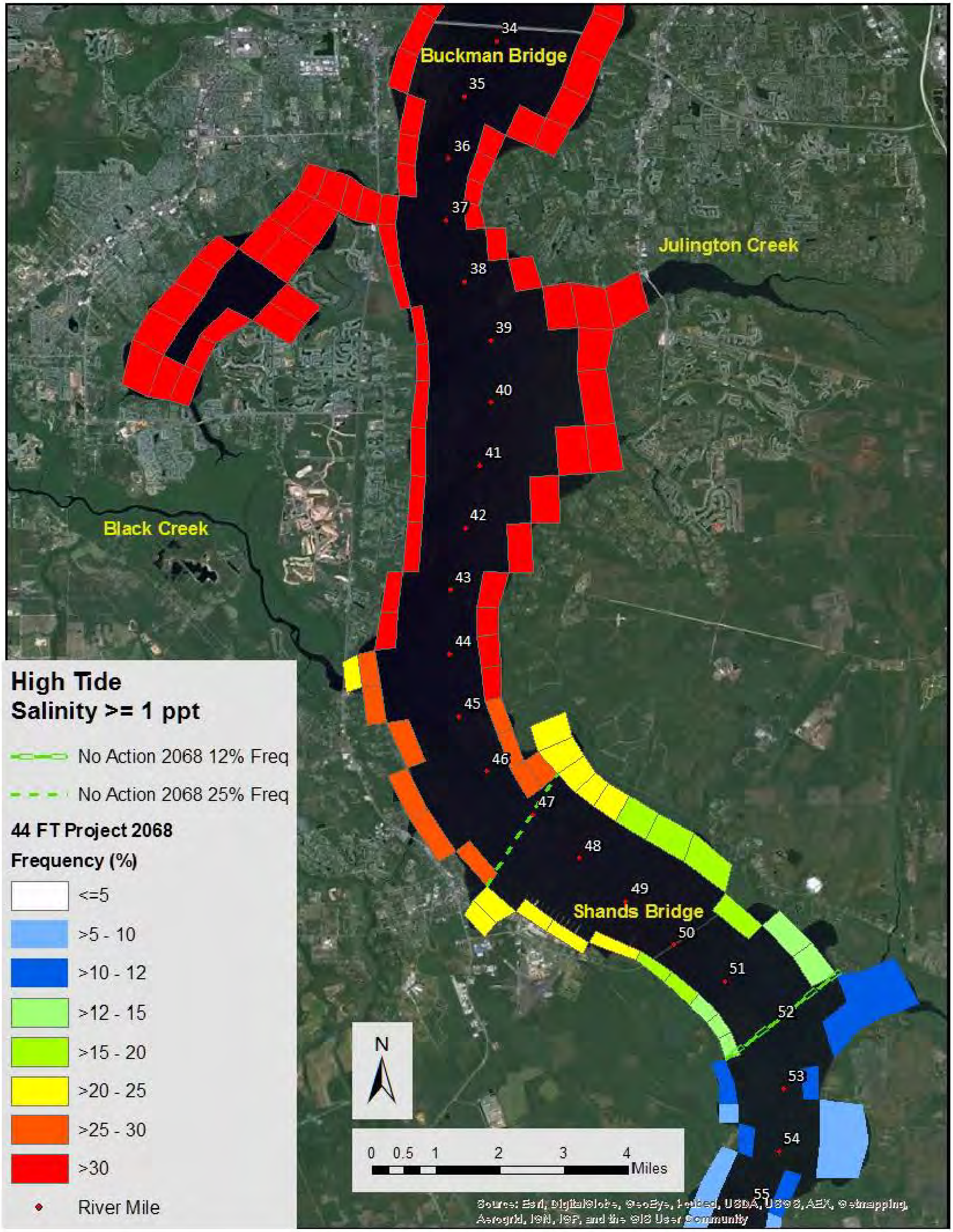

Figure 4.7 High tide >1 ppt Salinity Frequency, 50-Yr, 44-Ft Project

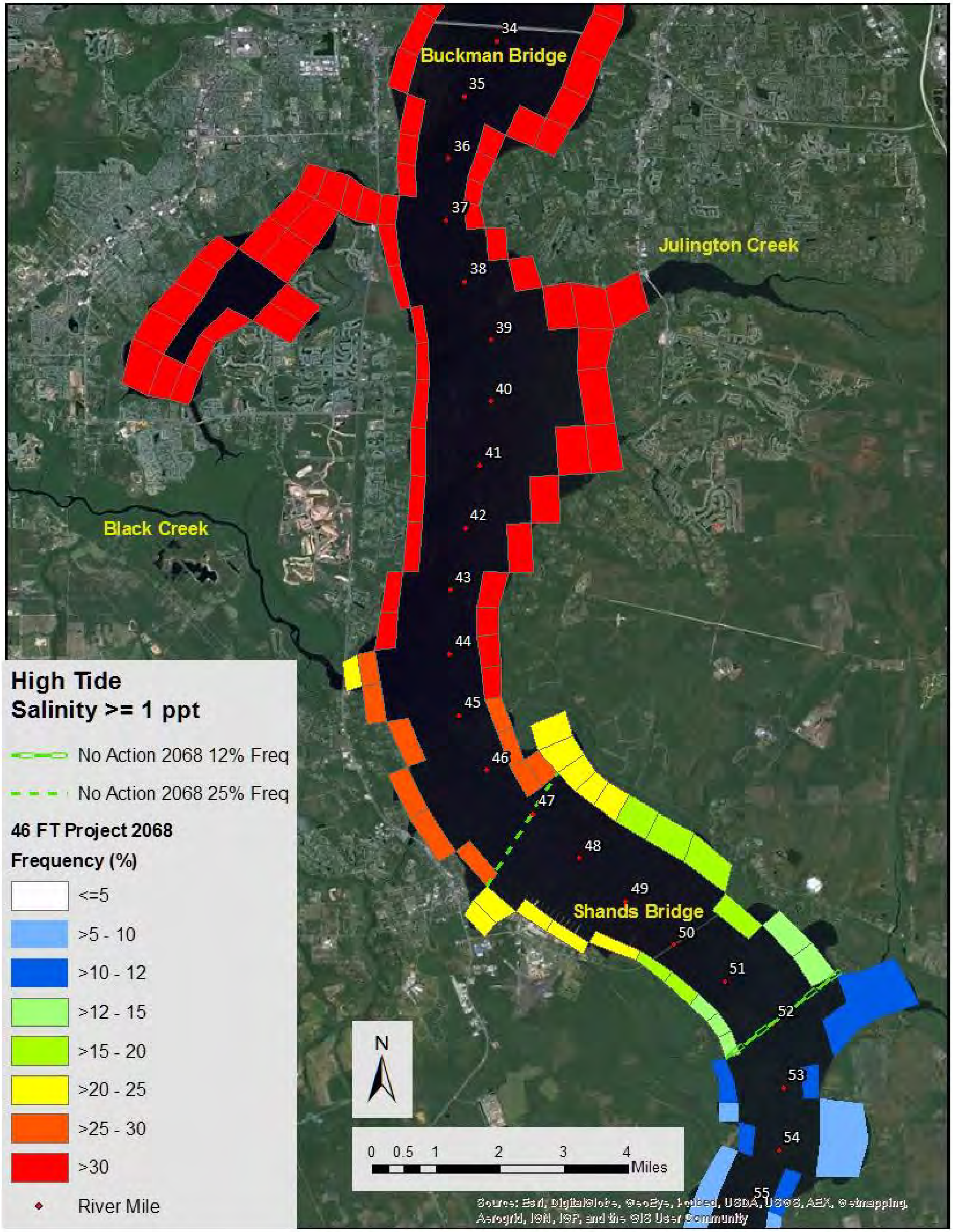

Figure 4.8 High tide >1 ppt Salinity Frequency, 50-Yr, 46-Ft Project

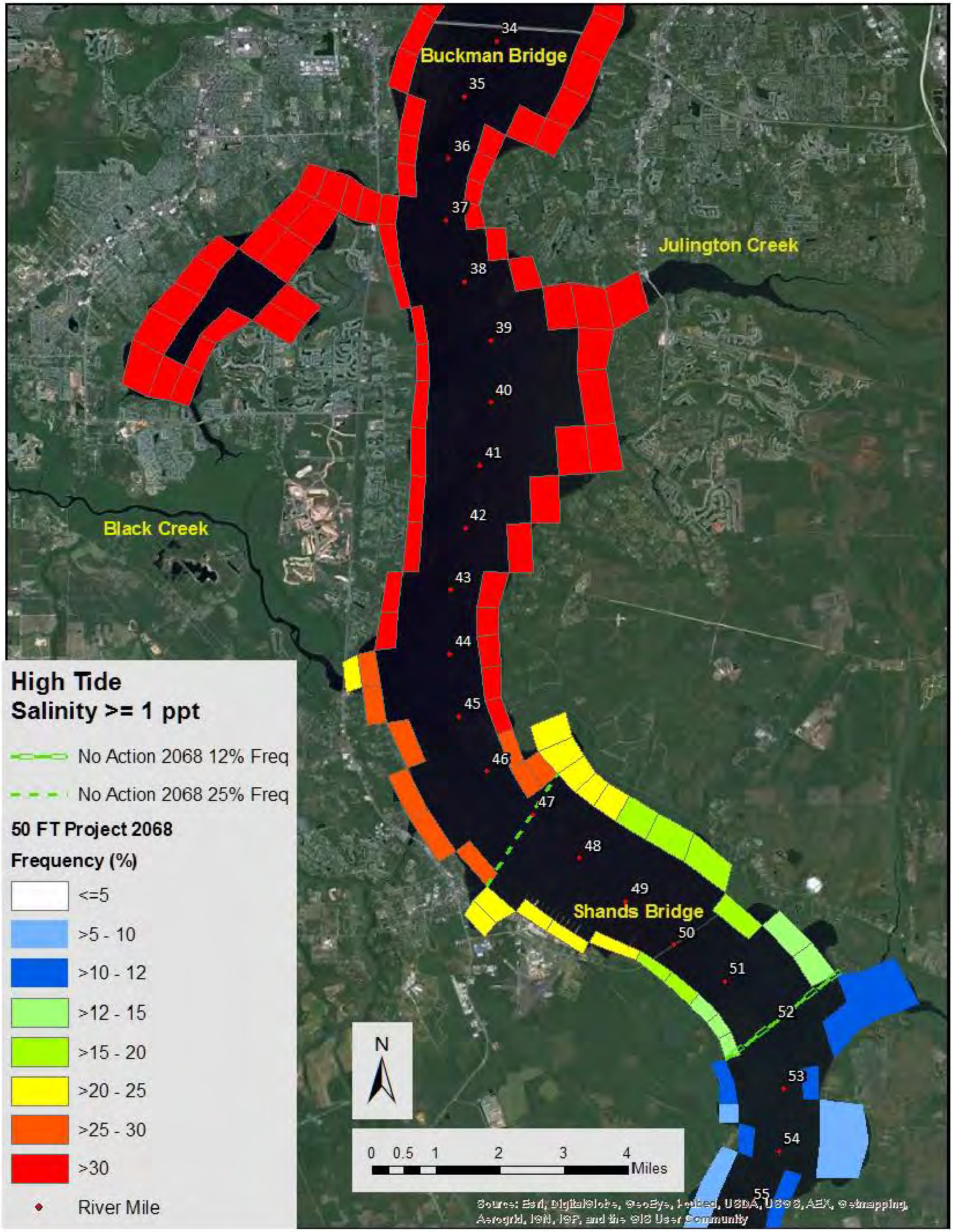

Figure 4.9 High tide >1 ppt Salinity Frequency, 50-Yr, 50-Ft Project

5.0 FISH

5.1 Introduction

The lower St. Johns River (LSJR) has a large, diverse fish community associated with the wide range of salinity conditions encountered in the estuary and tidally influenced areas of the river. Freshwater, estuarine marine, anadromous, and catadromous species are included in the species list. SJRWMD 2012: Chapter 12, pp. 12-3 and 12-44) summarizes the importance of this community:

> The fish community of the St. Johns River is a productive, diverse composite of freshwater, estuarine, and marine species populations. The LSJR fish community is a biologically unique community in North America because several estuarine species have established nonmigratory breeding populations in upstream freshwater reaches. The St. Johns River also supports some of the most valuable commercial and recreational fisheries in the state (Bass and Cox 1985; DeMort 1990; Holder et al. 2006; McLane 1955)..Two hundred and twenty-five fish species have been collected from the St. Johns River (Cox et al. 1980; MacDonald et al. 2009; McLane 1955; Tagatz 1968) — 63 freshwater species, 138 euryhaline species, and 24 marine species. Euryhaline species use the estuary for some or all of their life stages. Several species considered strictly estuarine inhabitants, including stingray (*Dasyatis* spp.), goby (*Microgobius* spp.), and pipefish (*Syngnathus* spp.), have established subpopulations that spend their entire life cycles within the freshwater portions of the river (Burgess and Franz 1978; Johnson and Snelson 1996).

Commercial fishing since the 1850s has been an important component of the local community (Miller et al.2012). Since the 1950s, commercial fishing has declined, but recreational sport fishing remains an important activity in the lower and upper river. Brody (1994) identified largemouth bass, black crappie, and other sunfishes (centrarchidae) as the main interests of sport fishermen in the LSJR. Striped bass and sunshine-striped bass, stocked from state-run hatcheries, maintain that fishery. Emergent and submerged vegetation provide key areas for game fishes. As noted in Brody (1994, p. 58), "When submerged and emergent aquatic vegetation are reduced, game fish populations are diminished." Popular saltwater or estuarine species for recreational fishing include red drum (Sciaenops ocellatus), spotted sea trout (*Cynoscion nebulosus*), black drum (*Pogonias cromis*), and Atlantic croaker (*Micropogonias undulatus*) (DeMort, 1990 as cited in Miller et al., 2012). Both Brody (1994) and Miller (2012) consider the LSJR fish community diminished over the past 50 years.

Miller et al. (2012) considered that water withdrawals from the middle and upper portions of the river could potentially affect fishes in estuarine reaches by reducing freshwater inflow and changing the spatial coverage and distribution of salinity zones. Such changes could directly influence estuarine fish distribution, abundance, and community structure. Inputs to the estuarine fisheries analysis from other working groups include potential changes in benthic macroinvertebrate communities, potential loss of SAV, and potential for increased phytoplankton blooms and a resultant decline in dissolved oxygen (SJRWMD, 2012: Chapter 12). Salinity changes in the LSJR due to channel deepening could also change the spatial coverage and distribution of salinity zones and affect estuarine fish communities as described above.

5.2 Methods

The USACE's intent for this study was to apply the methods developed by SJRWMD and described in Miller et al. (2012) to assess potential changes in the fish community resulting from water withdrawals in the middle and upper St. Johns River. The USACE wished to better understand the potential effects of salinity changes resulting from proposed deepening of the Federal channel in the first 13 miles of the St. Johns River. This study was unable to apply the methods that comprise the central focus of the WSIS assessment for fishes. The WSIS study applied data developed during almost 10 years of fish community field sampling conducted by the Florida Fish and Wildlife Conservation Commission (FWC) Fisheries-Independent Monitoring (FIM) program (MacDonald et al., 2009). As part of the WSIS efforts, analysts with the FWC used regression analysis to relate fisheries data from the FIM program to river flows (freshwater inflows) and developed quantitative relationships between fish species and "pseudospecies" (defined in Miller et al., 2012) abundances and river discharges. Miller et al. (2012) did not use salinity in the regression and correlation analyses because the wide salinity tolerances of many fish, their general mobility, and the rapid variability of salinity reduced its potential value to identify fish distribution patterns. In addition, Miller noted, "Freshwater inflow is also an easily quantifiable variable that will directly respond to water withdrawals." The statistical relationships developed from freshwater flows are not useful in developing salinity-abundance relationships.

The Venice System of salinity classification (Venice System 1959) defined estuarine salinity zones based on a consensus of practicing limnologists on the general characteristics of estuarine ecosystems based on different ranges of salinity. This system of classification has found very wide usage (including the WSIS study), but recently, some researchers have assessed the utility of this system. Bulger et al. (1993) found that estuarine fish species in the mid-Atlantic Region of the US tended to cluster in five zones roughly equivalent to the Venice system classes, but dividing the more saline part of the continuum into a range of

16-27‰ and another greater than 24 ‰. Briene et al (2008) studying estuarine health in the Netherlands, found that the Venice system provided a reasonable basis for salinity preferences of the fish community there. Greenwood (2007) reviewing and extensive database of Florida estuarine nekton samples, found "…little strong evidence for estuarine salinity zone as anything other than low salinities (0.1 – 1)".

Miller et al. (2012) used the six Venice system salinity categories (Table 5.1) to investigate effects of upstream water withdrawal on the LSJR. This assessment of salinity effect on fishes (and the assessment of salinity effects on benthic macroinvertebrates in the next chapter of this report) used the same Venice system salinity zones, with one additional zone: Salinity categories in this study included limnetic (< 0.5‰), oligohaline (0.5 ppt to 4.99 ppt), low mesohaline (5.0 ppt to 11.99 ppt), high mesohaline (12.0 ppt to 17.99 ppt), low polyhaline (18.0 ppt to 23.99 ppt) high polyhaline (24.0 to 29.99 ppt), and euhaline (≥30.0ppt) zones.

Taylor Engineering split the polyhaline zone (18.0 ‰ to 29.99 ‰) into two zones (18 ppt -23.99 ppt and 24.0 ppt -29.99 ppt) or two reasons. Dr. Paul Montagna, the project expert in benthic macroinvertebrate salinity relationships recommended the split to better identify possible salinity affinities in the estuarine and marine benthic macroinvertebrate communities. He noted that a number of estuarine species had salinity optima in the 18‰ to 24 ‰ (e.g. oysters) and that this additional range of salinity might help identify potential salinity shifts affecting estuarine biota. Also, initial examination of the baseline salinity simulations showed that the river morphology and the sill in the river where the channel abruptly changes from a deep narrow configuration to a shallow wide configuration (Taylor Engineering 2012: Figure 4.7) had a significant effect on the river salinities upstream and downstream of that sill. The channel morphology segmented river salinities, with the channel downstream of the sill often above 24 ‰, with the shallower area immediately upstream of the sill often containing salinities between 18 and 24 ppt. This was true for both bottom salinities and integrated water column average salinities.

The SJRWMD investigation looked at the LSJR estuary as extending from the mouth of the river to Buffalo Bluff upstream of Palatka (Table 1). Within the LSJR, the SJRWMD calculated the average river surface area associated with each salinity category in each year of the salinity simulation. It compared the annual average areas of each habitat in various water withdrawal scenarios to assess whether different alternatives caused significant changes in the area of the several salinity habitat categories. The ecological modeling for channel deepening applies the same salinity zone analysis for the various deepening scenarios.

This study applied GIS analysis of the estimated highest salinity condition of each year to estimate changes in the areas of salinity ranges in the river. The baseline simulation provided the highest 30-day, 60-day, and 90-day moving average (MA) salinity days of each year (see Appendix A for calculation details) input to ArcGIS for calculation of salinity breakpoints and salinity zone areas (Table 5.1). For the salinity breakpoint values shown in Table 5.1, ArcGIS provided salinity isolines (isohalines) for each year's data. The same software provided the area (salinity zones) between isohalines. Because the 30-day MA data provided the greatest differences between the baseline and project alternative conditions, those results are provided here. The analysis of salinity zones of the 50-year horizon alternatives used the same method.

Table 5.1 Salinity Categories

Salinity Zone (ppt)	Salinity Category	Salinity Breakpoint (ppt)
x<0.5	limnetic	
0.5 ≤x <5.0	oligohaline	0.5
5.0≤x<12.0	low mesohaline	5.0
12 ≤x <18.0	high mesohaline	12.0
18 ≤x <24.0	low polyhaline	18.0
24 ≤x <30.0	high polyhaline	24.0
X ≥30.0	euhaline	30.0

5.3 Results

Salinity Zone Changes

Salinity zones varied both in average area and by year (Figure 5.1). Salinities less than 5 ppt accounted for between 60 and 76% of the total project area (94,822 acres) in relatively wet years (1996 – 1998) and for 41% – 48% in relatively dry years (1999 – 2001), a 35% decrease in area from wet to dry years. In particular, the <0.5 ppt zone, which when present occupied the river main channel between the upstream end of the project area (just downstream of Lake George) to a location near Green Cove Springs varied dramatically. For the baseline, the average area of the <0.5 ppt salinity zone equaled 24,528 acres. In 1999, that zone included only 349 acres, and in the 2001 simulation, that zone did not exist.

The areas associated with salinity zones higher than 5 ppt varied somewhat less dramatically, but showed clear differences between years. Of the salinity zones between 5 ppt and 30 ppt, the 12 ppt –18 ppt zone increased by the greatest fraction between relatively wet years and dry years. The 12 ppt – 18 ppt zone included 3% to 8% of the total area in dry years and 12% – 13% of the total areas in wet years. The other, higher salinity zones also increased in area during the dry years. The three salinity zones between 12 and 30 ppt, with an average of about 5% each of total project area in the wet years, increased to between 6% and 13% of the total in wet years. The largest increase occurred in the 12 ppt – 18 ppt range. Salinities > 30 ppt showed the greatest fractional increase, accounting for 2.5% of the total in wet years and more than twice that area in dry years.

A comparison of each alternative (baseline, 44-ft Channel, 46-ft Channel, and 50-ft Channel) to its 50-yr horizon counterpart showed the amount each zone changed at the project 50-yr horizon (Figure 5.2). The <0.5 ppt and the 0.5 ppt – 5.0 ppt salinity zones lost acreage that was transferred to the other salinity zones. The zone of salinities 24 ppt – 30 ppt showed almost no changes between alternatives. This probably resulted from that salinity zone's location in the river — in the narrowest part of the river near Talleyrand Terminal. This area also includes an abrupt bottom elevation change from deep (> 35 ft) to relatively shallow (20 ft or less). The other channel deepening alternatives included similar patterns. Note also the similarity between the 44-ft and 46-ft channel depth alternatives (Figures 5.4, 5.5, 5.6, and 5.7).

When compared in terms of percent area changes (Figure 5.3), the two largest salinity zones (<0.5 ppt and 0.5 – 5 ppt) lost between about 4% and about 12% of their areas. The 24 – 30 ppt zone lost a small percent of area in each alternative, for the reasons discussed above.

Maximum average water column salinity zones changed with alternatives and time (the 50-yr horizon alternative results) in ways similar to those seen in the analysis of maximum bottom salinity zone changes in Chapter 6 (Benthic Macroinvertebrates). Generally, the alternative channel depths produced only small changes in the location of each salinity zone, typically by small shifts upstream (Figures 5.4 and 5.5: Maximum 30-day MA salinities for 1999 simulation; Figures 5.6 and 5.7: 50-yr Horizon Maximum 30-day MA salinities for 1999 simulation). In figures 5.5 and 5.7, the <0.5 ppt zone is constrained to an area of a hundred acres or so at the mouth of a small tributary. The rest of the river in that area has salinities between 0.5 and 5 ppt.

Note that the figures show the approximate northern and southern halves of the project area separately. The salinity zone boundary changes are small; a map showing the entire project area would obscure the changes. In addition, the figures do not show the 44-ft alternative. The 44-ft alternative changes were very similar to the 46-ft effects and therefore did not display effectively.

5.4 Potential Impacts of Channel Deepening on LSJR Fish Communities

The available analyses for the fish environment are consistent with similar analyses for benthic macroinvertebrates (Chapter 6) and SAV (Chapter 3). However, the analyses are insufficient to provide a clear understanding of potential effects of the deepening alternative on fish populations.

5.5 Recommendations

Additional analysis of the FIM dataset (MacDonald et al. 2009) to examine relationships between salinity and fish species and pseudospecies defined for the analysis of the lower river fish community (MacDonald et al. 2009; Miller et al. 2012) would provide direct relationships (if they exist). Salinity modeling in the marshes may shed additional light on potential changes in that marsh that could change the availability of fixed habitat (the appropriate salinity in the marshes at the appropriate season). Examination of salinity patterns in the main channel river adjacent to the access points to the extensive river mouth marshes could help assess the potential effect of salinity regime changes on salinity related behaviors in fish species / pseudospecies.

A number of species show very discrete cohort growth patterns, at least for recruitment and initial growth stages. This pattern allows direct examination of salinity and life history events in samples collected as part of the FIM dataset. Other species show clear periods of presence and absence, which may also serve as effective example species to consider salinity effects. Such analyses combined with salinity modeling of the marshes would do a great deal to clarify the potential effects of the proposed channel deepening alternatives.

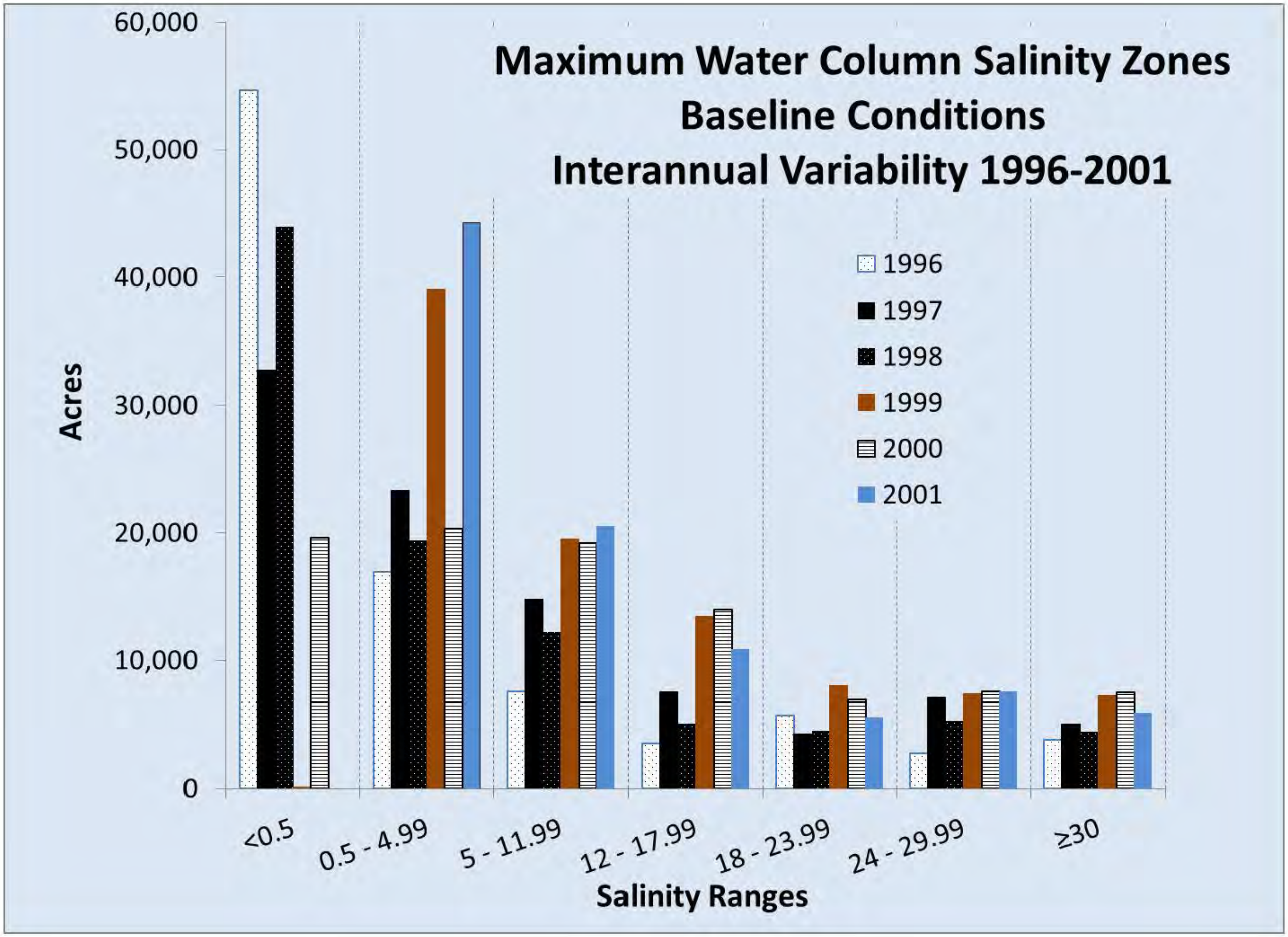

Figure 5.1 Inter-annual Variability of Salinity Zone Areas for Baseline Conditions.

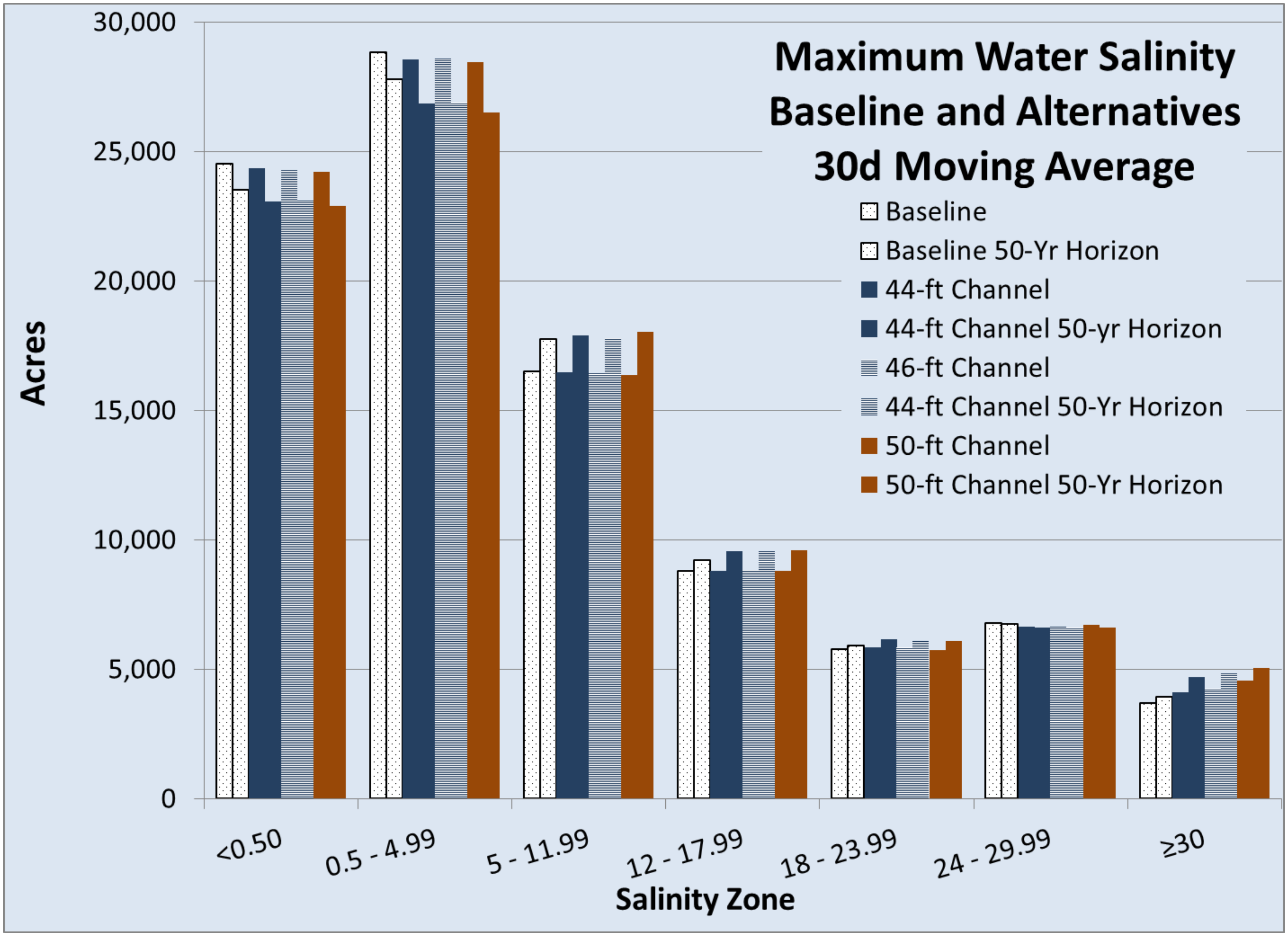

Figure 5.2 Comparison of Salinity Zone Areas for All Alternatives

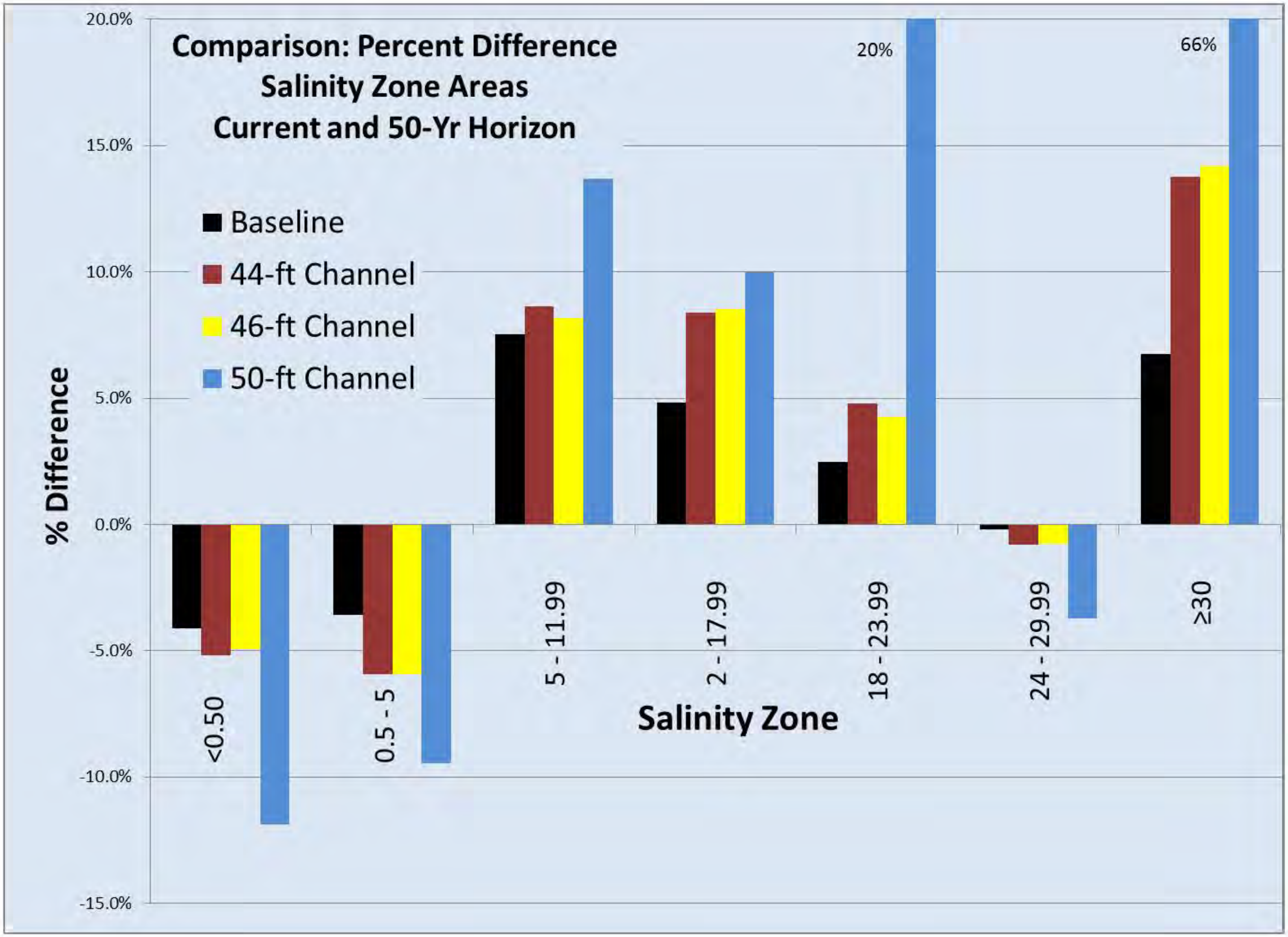

Figure 5.3 Average Percent Changes in Water Column Salinity Zone Areas from the Current to 50-yr Horizon Conditions for Each Alternative

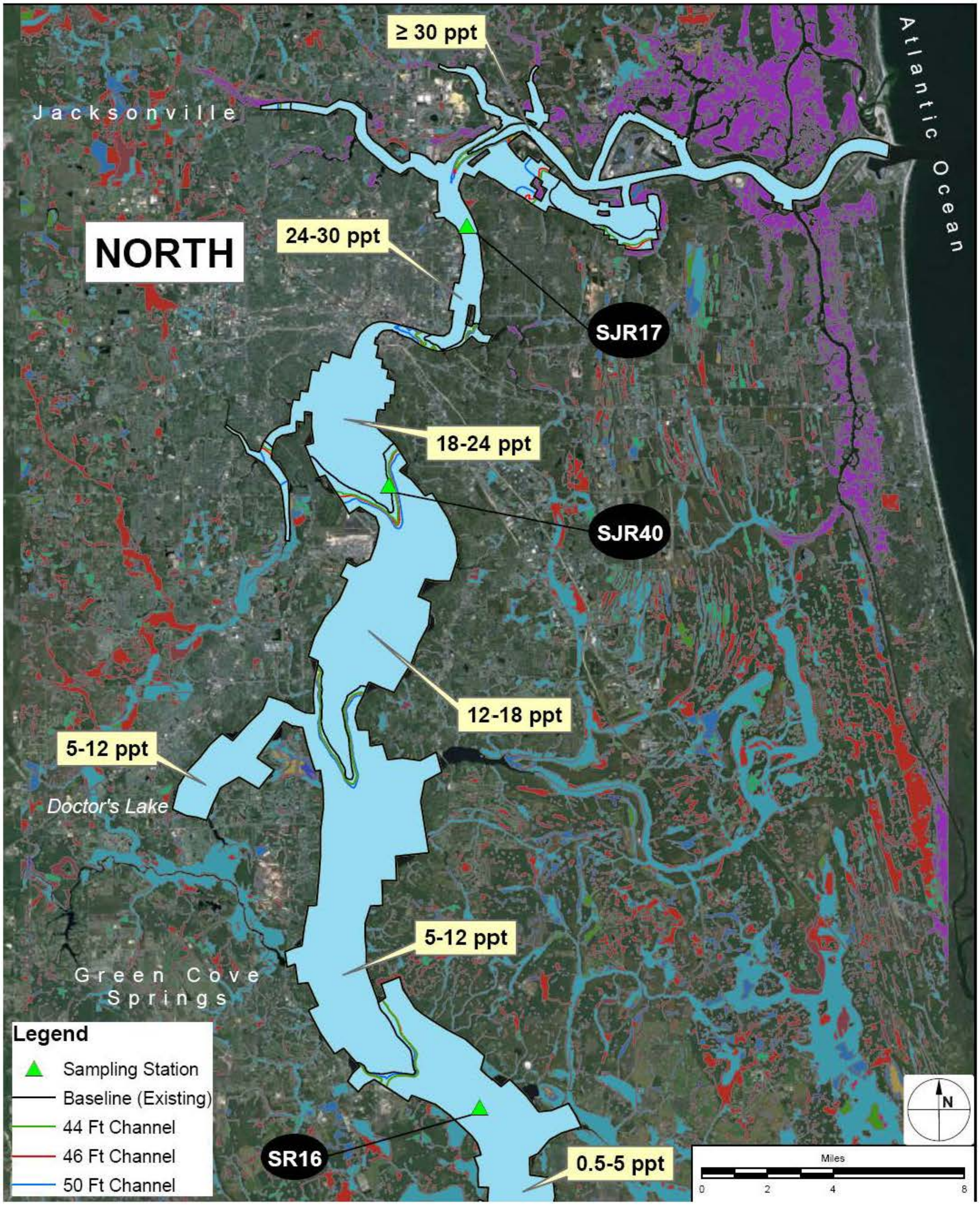

Figure 5.4 Baseline Maximum Water Column Salinity, LSJR North, 30-Day Moving Average, Baseline, 44-ft, 46-ft, and 50-ft Channels

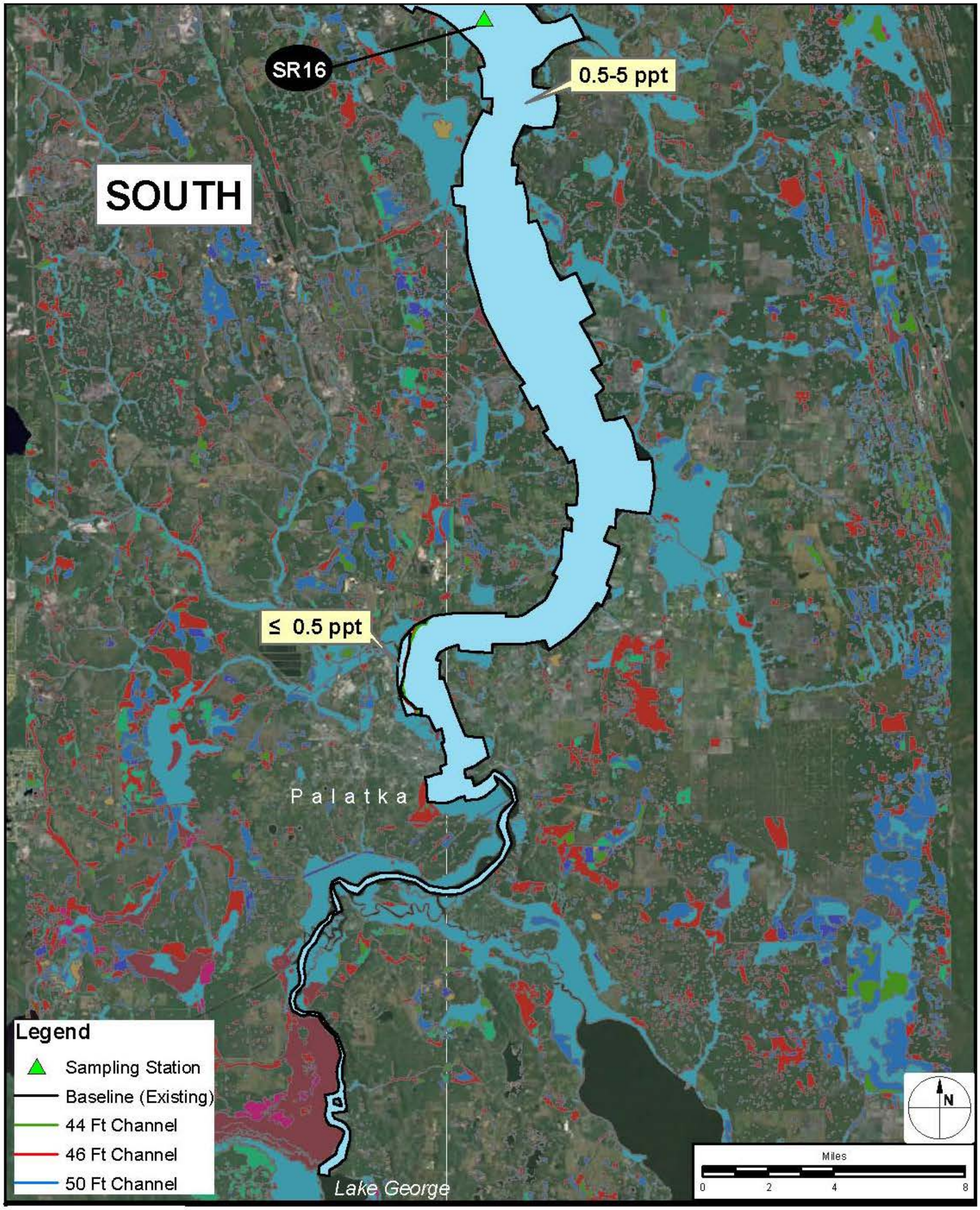

Figure 5.5 Baseline Maximum Water Column Salinity, LSJR South, 30-Day Moving Average, Baseline, 44-ft, 46-ft, and 50-ft Channels

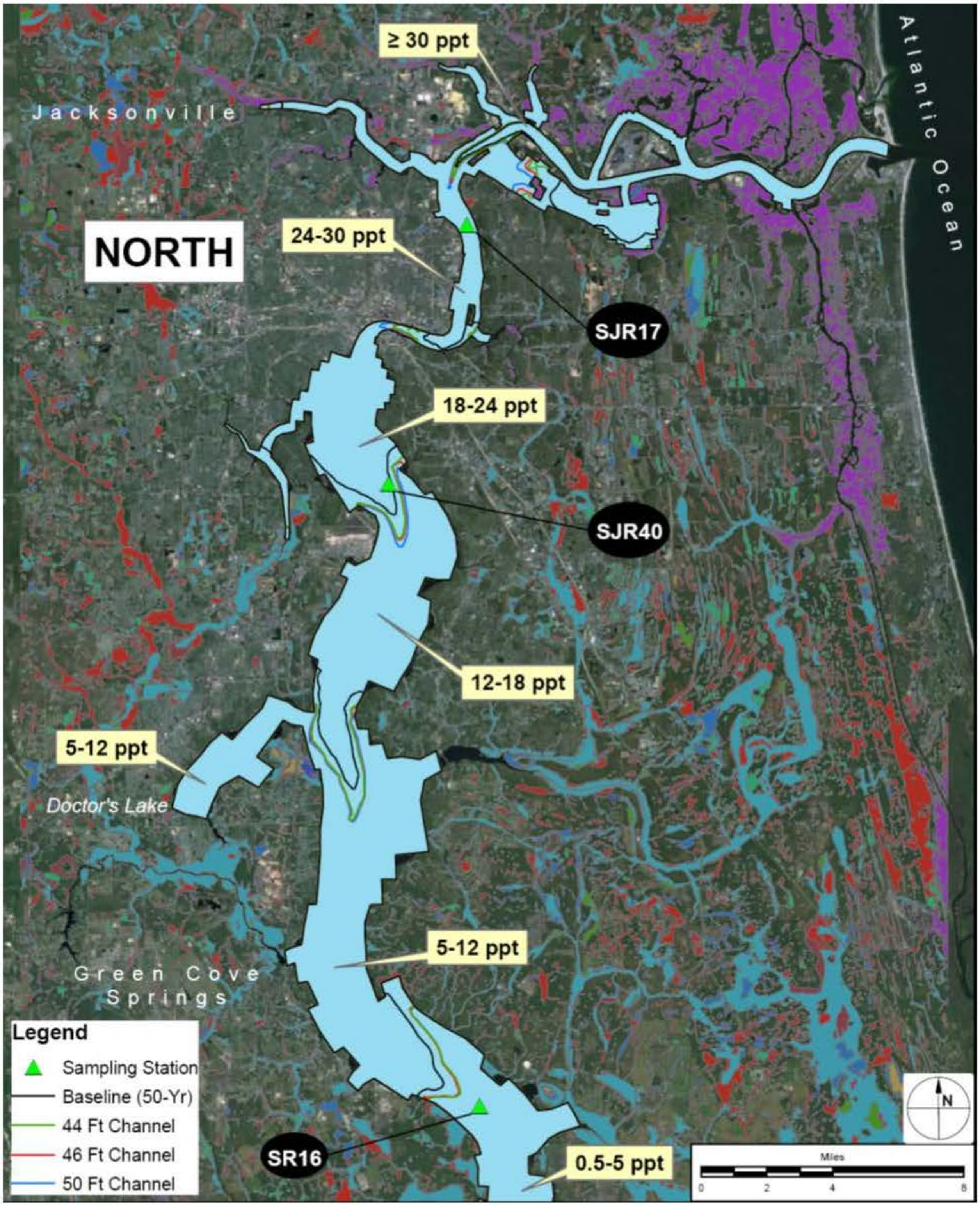

Figure 5.6 50-yr Horizon Maximum Water Column Salinity, LSJR North, 30-Day Moving Average: Baseline, 44-ft, 46-ft, and 50-ft Channels

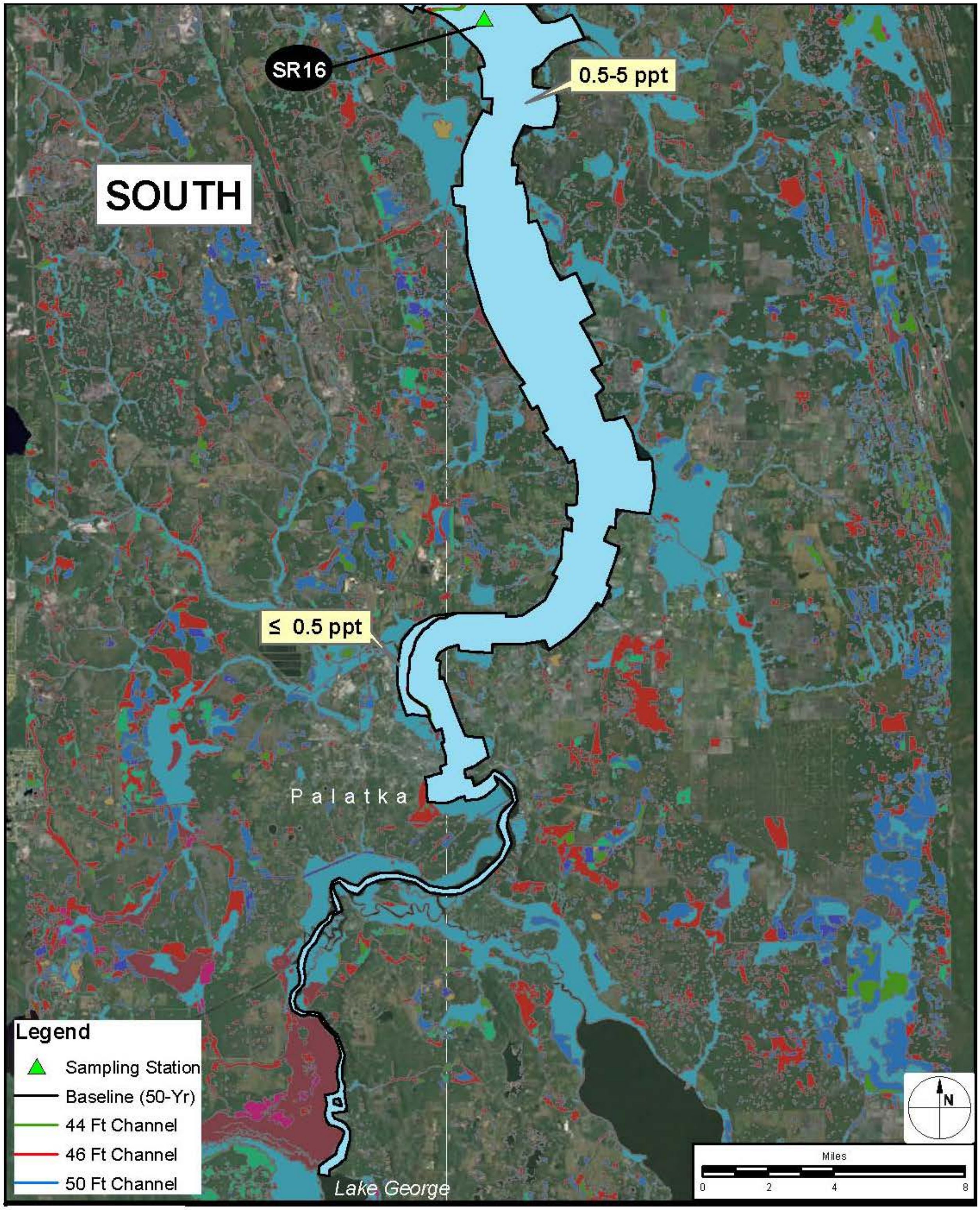

Figure 5.7 50-yr Horizon Maximum Water Column Salinity, LSJR South, 30-Day Moving Average: Baseline, 44-ft, 46-ft, and 50-ft Channels

6.0 BENTHIC MACROINVERTEBRATES

6.1 Introduction and Existing Conditions

Benthic macroinvertebrates (BMI) occupy an important place in the LSJR ecosystem, in the local fresh seafood economy, and in regional fishing recreation. Therefore, potential impact to this community as a result of proposed channel deepening requires analysis. This chapter presents results of analyses of channel changes that may affect BMI communities. The methods applied are those used by the SJRWMD in WSIS (2012). The interested reader should refer to Chapter 11 and Chapter 11 appendices of that report (Mattson et al.2011) to obtain an understanding of the BMI communities of the LSJR estuary.

Size and general body structure typically define BMI — invertebrate organisms retained by a mesh size of 200 to 500 μm (Stickney, 1984; Rosenberg and Resh, 1993). For this assessment, BMI will also include blue crabs (*Callinectes sapidus*) white shrimp, brown shrimp, and pink shrimp (*Litopenaeus setiferus, Farfantepenaeus aztecus*, and *Farfantepenaeus duorarum*), organisms that exceed size thresholds typically defining BMI. The importance of these species to the LSJR ecosystem and local economics warrants their inclusion in this assessment. Of the three shrimp species, white shrimp comprises by far the greatest portion of the shrimp population captured by commercial and recreational fishing efforts.

From a management perspective, BMI communities have provided biological indicators of water quality and integrity for decades (Gaufin, 1973; Rosenberg and Resh, 1993; Davis and Simon, 1995) and EPA has standardized protocols to sample BMI for this purpose. BMI have provided one means to assess habitat conditions, effects of hydrologic alteration, and water quality (e.g., Boon et al., 1992; Gore et al., 2001). A number of studies have correlated changes in salinity with changes in macrofauna abundance (e.g. Montagna and Kalke 1992, Montague and Ley 1993, Palmer at al. 2002), diversity (e.g. Mannino and Montagna 1997, Montagna et al. 2002), biomass (e.g. Rosenberg 1992, Kim and Montagna 2009) and community composition (e.g. Giberto et al. 2004, Mooraki et al. 2009, Strom and Thompson 2000). Applying available models of salinity-related community changes in the BMI community in the LSJR may provide a well-documented means of assessing effects of different channel deepening alternatives on the riverine BMI communities.

Deepening the Federal navigation channel (beyond its current 40-ft authorized depth) in the first 14 miles of the St. Johns River may elevate upstream salinities beyond those found under existing conditions. (See Chapter 1 and Chapter 8 for a full description of existing conditions as developed in the

EFDC salinity simulations for this project). Based on the WSIS study, elevated salinities that may impact the main stem natural communities are assumed to occur primarily upstream of the deepened channel, as the salinity in main river channel where the 40-ft channel occurs is already close to marine conditions.

Benthic macroinvertebrates transform primary production (live and detrital plant material) into animal biomass for use by higher trophic levels (Cummins et al., 2008). Estuarine and marine fishes use the BMI community as a key food source at a variety of life cycle stages. In addition to their role as primary consumers, shrimp (primarily white shrimp, *Litopenaeus setiferus*) and blue crab (*Callinectes sapidus*) provide a significant component of the local commercial seafood market. Recreational anglers also use traps and nets to capture these animals. Jacoby (2011) provides a synoptic review of the life histories of blue crab and the shrimp species listed above, including a discussion of the species' relationships between life stage, salinity, and habitat. Mattson (2012) provided a description of BMI communities in the St. Johns River, dividing the descriptions by WSIS river segment (See Chapter 1 Figure 1.2 for a WSIS river segment map). The river segments of interest for this report include Segments 1 – 3 (Mattson et al.2012: Figure 3.1), which comprise the main drainage channels for the LSJR watershed below Lake George.

Montagna et al. (2008, 2011), analyzed BMI data collected between 1974 and 1998 from 17 sampling stations in the LSJR estuary (downstream of Palatka, FL). The report provides detailed descriptions of the taxonomic composition of the various BMI communities, and statistical relationships of total abundance, taxon abundance, and salinity. Of the more than 545 species identified, 30 species comprised about 80% of the mean BMI abundance in the estuary. Abundance peaked at the lowest salinity sampled, and ranged from 250 / m^2 at Mill Cove, toward the mouth of the Estuary, to 12,000 per m^2 at a station approximately midway between the mouth of the river and the upstream-most sampling station near Palatka. The report applied multivariate analysis of the datasets under study to detail the species associations (defined by genera, family and phyla) at different salinity ranges, noting that eight "low salinity" communities occurred in mean salinities of 0.4 to 5.8 ppt (with one exception) and (with a single exception) nine high salinity communities occurred in waters of 13.6 ppt to 25.7 ppt salinity. The report includes details of salinity – abundance response models for the three parameter log normal model of salinity versus total abundance, 12 numerically dominant taxa, 30 numerically dominant species, and correlations between abundances and salinity for 17 dominant higher taxonomic categories.

Mattson et al. (2012) and referenced literature, in particular Montagna et al. (2008, 2011), provide detailed discussions of the BMI communities of the LSJR relevant to the channel deepening project. A short list of the some of the main general findings of those documents includes the following (Montagna et al.2008, 2011; Mattson et al.2012).

- Sampling of BMI in the LSJR has yielded 1,063 species of freshwater, estuarine, and marine invertebrates. Dominant taxa (by number of species) in freshwater reaches include aquatic insects, mollusks, and oligochaete worms. In the estuarine portion of the river, mollusks, crustaceans, and polychaetes dominate the species composition.
- The LSJR has seen a wide variety of sampling efforts but no routine, systematic, long-term (≥ 10 years) program. Of the 31 sampling efforts identified, 11 reported sampling in the lower basin, including 2 basin-wide sampling efforts and 9 focused only on the LSJR. Mattson et al.(2012) concluded that those 9 efforts provided more data than available in the middle and upper basins of the river.
- Because salinity "affects benthic communities primarily because of salinity regime alternations," "managing the inflows into estuaries" should include preservation of natural salinity regimes (Mattson et al., 2012)
- Individual taxa often exhibit nonlinear responses to salinity and many taxa exhibit optimal salinity ranges. In addition, some display linear or curvilinear responses to salinity gradients.
- Critical BMI habitats in the LSJR include submerged vegetation (*Vallisneria americana*), which can tolerate "moderate levels of salinity" (exposure to salinity of 15 ppt or more for more than a day or so).
- Dissolved oxygen (DO) is an important factor in distribution of BMI. Taxa more tolerant of low DO (e.g., chironomids and oligochaetes) sometimes required up to 30 days of low DO before experiencing lethal effects. In estuaries, DO below 2 to 3 mg/L could have severe effects on benthic community structure and function.
- BMI are key components in the diets of many fish species important as recreational or commercial fisheries.
- Many members of the BMI community in the LSJR project area are generally adapted to a dynamic salinity regime. High salinity communities tend to be numerically dominated by members of the Cnidaria, Echinodermata, and Chordata phyla, with fewer individuals of the Insecta (phylum Arthropoda). Polychaete genera tend toward high salinity conditions, with some genera much more prevalent in high rather than low salinity conditions. However, some polychaete genera occur almost exclusively in high salinity communities.
- Regardless of the taxonomic level selected to represent community composition, BMI community composition show higher correlations to salinity than to other variables tested (DO, pH, and temperature).

- Nonmetric multidimensional scaling (MDS) analysis found that the dataset clustered in two main groups representing low salinity sites (0.4 ppt – 5.8 ppt) and higher salinity sites (13.6 ppt to 25.7 ppt). Regression of abundance (number of individuals per m^2) against salinity showed abundance peaking at a mean salinity of 0.4 ppt. Reduced abundance in the lower reaches of the estuary (river segments 1 and 2) likely occurs because of greater salinity variability and the related physiological stresses occurring there, as well as pollution from the urban environment.

The mouth of the St. Johns River and the associated marshes and open waters comprise part of the Timucuan Ecological and Historic Preserve (TIMU) a unit of the National Park System established in 1988. TIMU "encompasses 46,000 acres of salt marsh and coastal hammock habitat in addition to marine and brackish open waters...and contains the seaward confluence of the Nassau and St. Johns Rivers" (http://www.npca.org/parks/timucuan-ecological-and-historic-preserve.html). Those marshes associated with the St. Johns River include almost all of the estuarine (*Spartina alterniflora / Juncus romerianus* dominated) marshes within the ecological modeling study area. These marshes serve as nursery areas for a wide variety of marine and estuarine fishes and invertebrates, including species important to humans.

Hymel (2009) described the TIMU marshes as "heavily influenced by urban areas (City of Jacksonville), manufacturing (pulp and paper mills), petroleum storage, shipping (Port of Jacksonville; JAXPORT), military bases (Naval Station Mayport), power stations (Jacksonville Electric Authority), and recreational activities on the Nassau, Ft. George, and St. Johns rivers". She summarized benthic macroinvertebrate studies in TIMU and the nearby lower St. Johns River main channel by Long (2004), Landsberg et al. (2004), Anderson et al. (2005), and Evans et al. (2004). Those studies suggested that over the past 20 years the marsh has shifted from relatively low salinity pollution-sensitive to higher-salinity, pollution tolerant taxa (Long 2004). Evens et al. (2004) concluded that BMI communities in the river upstream of TIMU and within the City of Jacksonville (located near Bolles School, the Naval Air Station, Doctor's Lake, and Pirates Cove) consisted of low diversity, pollution tolerant associations. Clapboard Creek, Dunn's Creek, and Broward River BMI communities had moderate diversity with pollution tolerant species. Hymel (2009) also identified invasive species introduced by ships traveling through JAXPORT as an emerging concern for TIMU.

Gregory et al. (2011) reported water quality and sediment quality in the TIMU as generally "Good" and "Fair" respectively. Most of the lower quality findings related to excess phosphorus, nitrogen, and chlorophyll a in the water and nutrient rich sediments, as well as some sites with high levels of total organic carbon (TOC) in the sediments. He noted that the sites with elevated nutrient conditions tend to occur "in the more upstream reaches of the Nassau River and St. Johns River as well as inland areas along Clapboard Creek." Fair and Poor sediment conditions "due to elevated TOC were generally observed in more inland and riverine areas of TIMU."

Wright et al. (2012) reported 2011 salinities at a water quality sampling station in Clapboard Creek (located within TIMU on the north side of the river slightly downstream of the JEA North Power Plant) ranging between about 11 and 35 ppt with the vast majority of the data between 25 ppt and 35 ppt.

6.2 Potential River Deepening Effects on Macroinvertebrates

If deepening the channel caused an upstream salinity shift of the baseline salinity gradient, this shift could cause an equivalent upstream shift in communities and taxa, to the extent of individual BMI taxon sensitivities to changes in salinity. Montagna et al. (2011: Table 5) found that for lower St. Johns River species, genera, families, and phyla tested, salinity generated the highest Spearman Correlation Coefficient of the variables salinity, temperature, pH, and dissolved oxygen. However, the research also found the communities sampled included two main clusters, each salinity tolerant within a fairly wide range. The results suggest that if upstream salinity shifts were to occur, estuarine and possibly marine salinity communities would expand to the detriment of freshwater BMI communities they would replace. That shift might occur as a gradient of community change along the new salinity gradient, as some species within the low salinity community have more tolerance than others for increased salinities. In addition to shifting communities upstream, the shift could move the optimum salinity range for some species away from the optimum (fixed) habitat for those species. However, the BMI species are generally characterized by small, very rapidly reproducing, very fecund species; BMI species are typically assumed to produce many more offspring than will ultimately survive in any case. For the LSJR, the large inter-annual variability in salinity gradients probably exerts a dominant effect on most BMI distributions. In addition, much of the estuarine portion of the river runs through the City of Jacksonville and urbanization has tended to reduce the acreage of key estuarine habitats such as marshes. Thus, salinity shifts within the urbanized area may not represent a significant change in available habitat. The high salinities reported in the TIMU marsh station in Clapboard Creek (located relatively near to adjacent uplands and away from the river main channel) may reflect general conditions in the marshes adjacent to the main channel. Again, salinity shifts in this area may be minor or insignificant, as the area appears to experience high salinities under most conditions most of the year.

Vallisneria americana (eelgrass) the primary freshwater submersed vegetation in the LSJR extends downriver to about river mile 25 (Chapter 3). Impacts to eelgrass, a habitat relatively high in BMI diversity, could occur if the salinity gradient were to shift upstream. The unvegetated benthic habitat that accounts for most of the river bottom could also experience a shift in species composition with an upstream shift in the salinity gradient. Shifts from less to more saline conditions tend to reduce BMI diversity and total abundance (Montagna et al. 2011) However, eelgrass occurs only along the shorelines and thus covers a relatively small fraction of the total BMI habitat. Thus, unvegetated habitat would account for most of the standing stock or abundance reduction due to salinity changes.

6.3 BMI Analysis Methods

To assess impacts of altered LSJR salinity regimes on the BMI community, the analyses used in this study use, to the extent possible, the same methods as those SJRWMD used to assess impacts of upstream water withdrawals. SJRWMD described these methods in the WSIS (Mattson et al. 2012). The USACE and Taylor Engineering reviewed that WSIS chapter, related appendices, and referenced documents. The USACE project team concluded that most of the BMI analysis methods were as useful for assessing the effects of salinity changes as they were for the SJRWMD to assess potential changes in freshwater inflows to the estuary.

This BMI analysis compares the baseline condition to each alternative separately, followed by consideration of the relationship between different alternatives. The BMI effects assessment also considers the results of the Submerged Aquatic Vegetation analysis (SAV: Chapter 4 of this report) to identify potential effects on BMI of salinity-related impacts to SAV from channel deepening alternatives. Mattson et al. (2008) identified salinity as a primary variable in BMI community composition within SAV.

6.3.1 BMI Taxa Population and Community Abundance and Salinity

Although many estuarine organisms generally have a wide salinity tolerance (from 0 to 30 psu - euryhaline), most are located within only a portion of their potential salinity range or have a distribution focused on a specific salinity range. Thus, salinity gradients play a major role in determining the distribution of estuarine organisms (Montagna et al. 2011). Secondary production of estuarine benthic macrofauna in particular is known to increase with increases in freshwater inflow and salinities that range 15 – 20 psu (Montagna and Kalke 1992). Salinity gradients also can act as barriers to predators and disease. Two important oyster predators in Gulf of Mexico estuaries, the southern oyster drill, *Thais haemastoma,* and the stone crab *Menippe mercenaria* are intolerant of sustained salinities below 15 psu (Menzel et al. 1957; MacKenzie 1977). Freshwater inflow, depending on the volume, can dilute or even eliminate infective *Perkinsus marinus* oyster disease particles in low salinity areas because disease organisms prefer salinities above 25 psu (Mackin 1955; La Peyre et al. 2009). The timing of freshwater inflows is also important to estuarine organism abundance and distribution because the organisms have evolved over long periods to particular regimes of freshwater inflow and associated salinity conditions such that there are breaks in tolerances of various BMI below 15 psu, around 20 psu, and 25 psu (Montagna et al. 2002). To examine changes in space occupied by different salinity zones, this analysis applied SJRWMD salinity breakpoints of 0.5, 5, 12, 18, and 30 ppt salinity, and added an additional breakpoint at 24 ppt salinity. To help link consideration of spatial changes in salinities at specific locations probabilities of salinity durations considered at the three sites included 0.5, 1, 2, 3, 4, 5, 12, 18, 24, and 30 ppt. The additional salinity break points 1, 2, 3, 4, and 5 ppt provided more details about the changes at the upstream end of the LSJR estuarine salinity.

Baseline maximum daily bottom salinity day identified from 30-day, 60-day, and 90-day moving average values of daily salinity maxima provided the moving average (MA) day used to calculate salinity zones and areas. Appendix B (from Taylor Engineering, 2012) provides a detailed description of the moving average calculation process. The salinity calculations varied somewhat from the SJRWMD approach. Because the bottom layer lies closest to the sediments sampled for BMI abundance, we selected bottom layer salinity values to calculate BMI salinity zones, rather than using the maximum water column salinities as done in the WSIS. We selected an additive set of moving average periods for the BMI and Fish Assessments (Chapter 7) to provide the best opportunity for consideration of linkages between BMI and fish community changes. The SJRWMD WSIS study used 30-, 60-, and 120-day moving average periods.

GIS analysis transformed the model cell output data to salinity isohaline lines and polygons used to define salinity ranges (Table 6.1)

Table 6.1 Salinity Breakpoints and Related Salinity Ranges for Salinity Area Estimates

Salinity Breakpoint (ppt)	Salinity Zone Range (ppt)	Salinity Category
	x<0.5	limnetic
0.5	0.5 ≤x <5.0	oligohaline
5.0	5.0≤x<12.0	low mesohaline
12.0	12 ≤x <18.0	high mesohaline
18.0	18 ≤x <24.0	low polyhaline
24.0	24 ≤x <30.0	high polyhaline
30.0	≥X30.0	euhaline

GIS analysis calculated and mapped the area associated with each salinity zone (Table 6.1) for baseline and alternative scenarios. For the baseline scenario, the lowest salinity range (x<0.5 ppt) included the model upstream boundary cell just downstream of Lake George to the 0.5 ppt isohaline line downstream. The euhaline salinity range (≥30 ppt) comprised the space between the calculated 30 ppt isohaline line and the mouth of the river. The EFDC model grid predicting salinities extends into the offshore coastal shelf of the Atlantic Ocean; these cells did not enter into the calculation of salinity zones. The SJRWMD and USACE analyses were similar in this respect, with only slight differences associated with the upstream and river mouth terminus points for the analysis. SJRWMD (2012: Chapter 11) used a single zone for the salinity values between 18 ppt and 30 ppt and did not include the area greater than or equal to 30 ppt. This assessment separates the 18 ppt to 30 ppt salinity zone into 18 ppt – 24 ppt and 24 ppt – 30 ppt because many estuarine invertebrates have salinity optima between 18 ppt and 24 ppt salinity (Paul Montagna, personal communication, September 14, 2012). Changes in the location of the 18 – 24 ppt zone may reflect more or less high quality physical habitat space for estuarine species. The consideration of a ≥30 ppt zone, absent from the SJRWMD report, provided a more complete picture of the potential for upstream movement of ocean salinity conditions after channel deepening.

The mean and 95% confidence interval for each salinity zone area in the project baseline and alternative data sets provided a comparison tool to assess differences between years within moving average categories and salinity zones. This tool provided a possible means to assess differences between the baseline and each alternative.

The salinity zone area data provided the means to estimate changes in total BMI community abundance by salinity zone. Montagna et al. (2011) developed equations to estimate changes in total BMI community abundance with salinity in the LSJR. Mattson (2012) described a spreadsheet model of BMI abundance constructed with the equation

$$Y = ae^{\left[-0.5\left(\frac{ln\left(\frac{x}{X_C}\right)}{b}\right)^2\right]}$$ Equation 1

Where Y = a biological characteristic (abundance)

X = salinity

a= maximum value of the biological characteristic

b = skewness or rate of change of the response as a function of salinity

X_c = the peak response value on the salinity axis

ln = natural log function

e = exponential function

The BMI analysis reported here used the SJRWMD EXCEL spreadsheet version of this nonlinear model (Ed Lowe, SJRWMD, personal communication email, April 6, 2012) to calculate BMI community abundance estimates for each salinity zone area. The BMI density (number / m^2) for each salinity zone calculated using equation 1 above provided the base BMI density value against which to calculate density changes. The spreadsheet calculated a baseline BMI density. That baseline value was multiplied by the percent difference in area of each salinity zone (Table 6.1) in the baseline and alternatives to identify the change in density. The baseline value minus the density change value provided the density for the salinity zones of each alternative scenario. Impact assessment compared alternatives' effects on BMI density with respect to the baseline condition and the changes in the physical location of each salinity zone in each alternative.

Calculating the difference between baseline BMI density in each salinity zone and the BMI density in each salinity zone of each alternative yielded the changes in BMI community density (number of individuals per m^2) by scenario by salinity zone.

6.3.2 Partial Duration Frequency Analysis of Salinity

Partial Duration Frequency Analysis (PDFA) of salinity in the LSJR (Mattson et al. 2012) detailed the changes in salinity level and duration at three locations within river segment 2 (see Figure 1.2, for river segment boundaries) which locations also served as sampling stations for BMI. This study performed PDFA at the same locations (Figure 6.1 PDFA Analysis Station Locations) to describe the extent and intensity of salinity changes occurring as a result of project alternatives. The USACE also selected these locations because a clear salinity – freshwater boundary for SAV occurred between the most upstream and downstream-most of the three stations. In addition, preliminary USACE salinity modeling results suggest that many of the effects might occur within the river within the upstream and downstream boundaries.

Slater et al. (2011) provided a detailed mathematical description of PDFA that the interested reader should review to best understand this method. For this study, Taylor Engineering used the mathematical description found in that document to develop a spreadsheet model for PDFA analysis at the same locations used by SJRWMD (Table 6.2). The input salinity data included single cell maximum daily bottom salinities for the period of record used in the analysis (six years, 1995 – 2001 inclusive) at three locations.

Table 6.2 Locations of Salinity Data Used for PDFA Analysis From Mattson Et al.(2012).

Site	Modeled Station Name	Latitude	Longitude	River km (mile)
JAXSJR17	JAXSJR17	30 deg 22.0 min	81 deg 37.1 min	29 (18.0)
JAXSJR40	JAXSJR40	30 deg 15.1 min	81 deg 39.1 min	47 (29.2)
SJSR16	SR16	29 deg 58.6 min	81 deg 36.6 min	81.7 (50.8)

Frequency analysis estimates how often, on average, a given event will occur. For this analysis, “on average” meant annually. If annual series hydrologic data provide the data to generate the statistics, frequency analysis estimates the probability of a given hydrologic event happening in any given year (Slater et al., 2011). For salinity data used here, PDFA analyzes the data record (in this case the entire six years of simulation days) to identify what period (length of days) and number of times a given salinity was exceeded. The results are divided by the number of years to produce an annual exceedance probability. The return interval for the same exceedance was defined as basically the inverse of the annual probability. The Weibull plotting position formula was used to create frequency and return interval plots.

The PDFA analyses compared the probability of a given salinity level event compared to the baseline behavior to provide an understanding of the salinities at which changes salinity regimes occur at a location and to show differences between salinity durations of the baseline and a project alternative for the same salinity.

Assessment of water withdrawal effects on blue crab and shrimp populations employed a regression relationship between lagged inflow (the sum of SJRWMD discharge near Deland and the Ocklawaha River flow downstream of Kirkpatrick Dam), and crab and shrimp population data. While appropriate to assess water withdrawal effects, these regressions do not assess salinity effects. This report includes a summary of the last quarter century (1986 – 2011) of blue crab and white shrimp landings for the five counties with borders on the LSJR (Nassau, Clay, Duval, St. Johns, and Putnam) as a means to scale the importance of these commercial fisheries. Note that due to restrictions on commercial shrimping methods in most of the LSJR, landings are associated almost completely with catches from the Atlantic Ocean. However, white shrimp (as well as brown shrimp and pink shrimp) conduct key parts of their life cycle in the LSJR estuary and are considered here for that reason.

USACE also considered the effects of salinity-based changes in SAV (principally eelgrass, *Vallisneria americana*) cover on BMI. This chapter will also include a review of potential effects of BMI from SAV changes identified in Chapter 4 of this report.

6.4 Results

6.4.1 Salinity Zones and BMI Community Abundance

This analysis used the daily maximum bottom salinity values to calculate 30-day, 60-day, and 90-day moving average (MA) salinities for all cells in the simulation. The daily maximum salinity is the highest salinity in the hourly model output for each day. The highest MA day for each year in the baseline simulation provided the model salinity data to calculate salinity zones in the project area for each year. Initial comparison of the three MA datasets revealed that the 30-day MA dataset included the greatest changes between years. This is not surprising, as the longer MA time periods reduce variability in the resulting MA datasets. Thus, the 30-day MA results are used here to assess changes in salinity and potential impacts of those changes. Because of high inter-annual variability in the salinity zone areas (Figure 6.1) and because the maximum bottom salinities as calculated already represent a relatively extreme view of bottom salinity dynamics, we used the six year average of maximum salinities or a single year, 1999, to illustrate bottom salinity dynamics. The year 1999 was the first dry (low rainfall) year of three (1999, 2000, and 2001) drought years modeled of which 2001 was the driest.

Average annual baseline maximum bottom salinity zones (Figure 6.1: 6-year average 30-day MA salinity zones) show the general pattern reflected in all alternatives. At the downstream end of the estuary, the baseline maximum bottom salinity zone ≥30 ppt extended well into downtown Jacksonville. The Talleyrand Terminal stretch of the river saw maximum bottom salinities between 18 and 24 ppt. Maximum bottom salinities below 18 ppt did not occur until just downstream of Doctors Lake. While most of Doctors Lake remained in the 0.5 ppt – 5.0 ppt range, salinities in the main channel around Doctors Lake remained between 5 and 12 ppt. Salinities fell below 5.0 ppt near Green Cove Springs and below 0.5 ppt between Green Cove Springs and Palatka (Figure 6.1).

Considering inter-annual variation in baseline condition salinity zone areas (Figure 6.2), the greatest changes occurred in the salinity zone <0.5 ppt at the upstream end of the study area. The LSJR estuary study area salinities (zones of annual maximum 30-day average bottom salinity days for the years 1996 – 2001 inclusive) considered in this analysis never fell below 0.23. In very low rainfall years (1999 and 2001) the lowest salinity zone (<0.5 ppt) at the upstream end of the study area decreased significantly in area (from 43,137 acres in 1998 to 108 acres in 1999) and subsequently disappeared (from 18,988 acres in 2000 to no area in 2001). The greatest change in zone area for those years was associated with increases in the ≥0.5 – 4.99 ppt salinity zone area. The size of the other zones did not vary so dramatically (Figure 6.2), but in general, slight expansions of salinities 12 ppt and higher balanced reductions in the lower salinity zones areas.

A plan view of the shifts in salinity zones shows small changes in location when comparing the baseline, 46-ft, and 50-ft channel depth simulation salinity boundaries (Figures 6.3 and 6.4). Note that the figures do not include the 44-ft alternative boundaries. Those boundaries lie very close to and downstream of the 46-ft alternative boundaries and makes boundary distinctions very difficult.

Upstream shifts in salinity zones at the project 50-year horizon (Figure 6.5 Comparison of Baseline and 50-yr Baseline Horizon Salinity Zones, LSJR North and Figure 6.6, Comparison of Baseline and 50-yr Baseline Horizon Salinity Zones, LSJR South) are similarly small, as are shifts at the 50-yr horizon resulting from resulting from different channel depth alternatives. Note again in the 50-yr horizon alternative figures, the 44-ft alternative does not occur as it lies very close to and immediately downstream of the zones created by the 46-ft alternative).

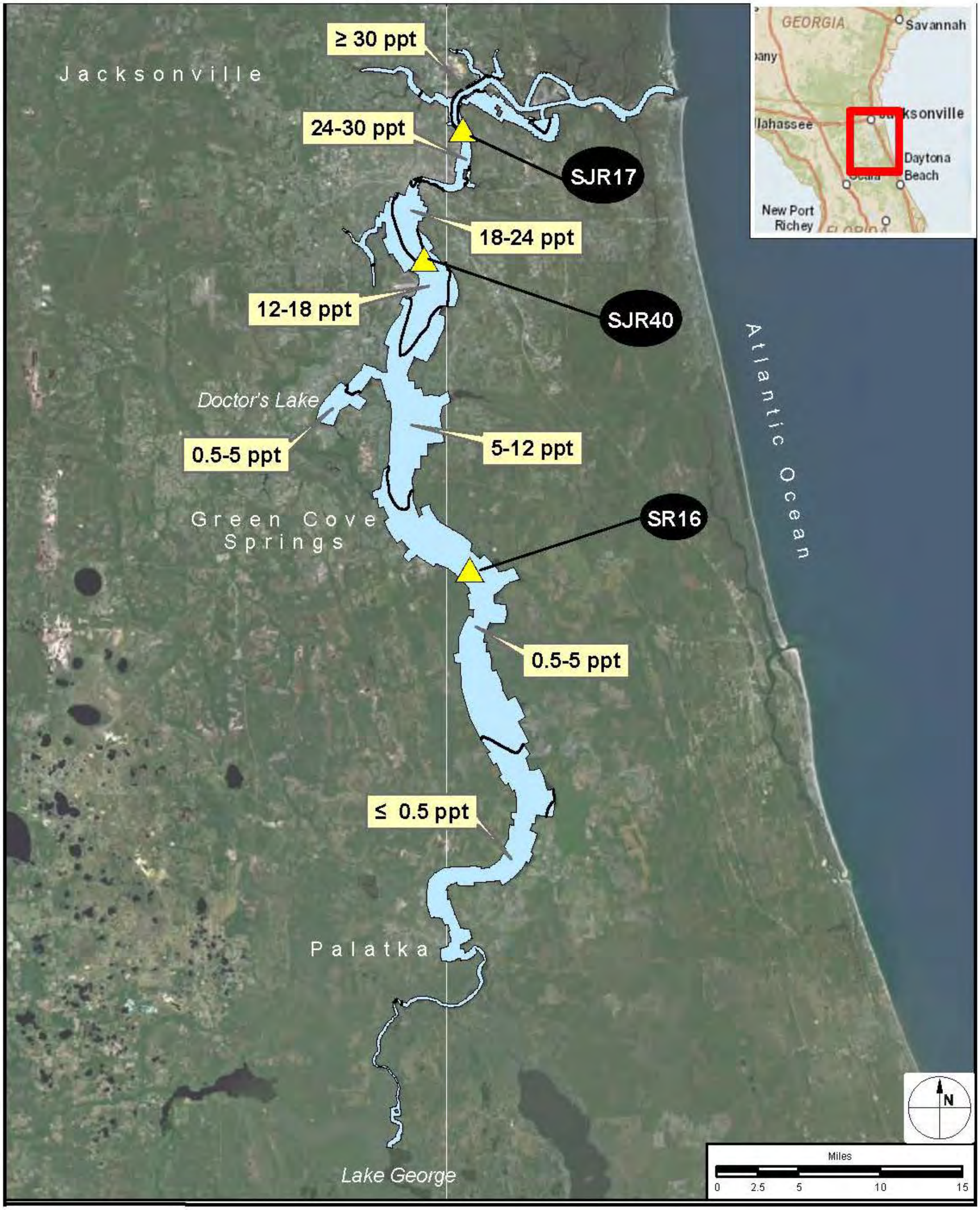

Figure 6.1 Maximum Bottom Salinity, LSJR, 30-Day Moving Average, Baseline Simulation

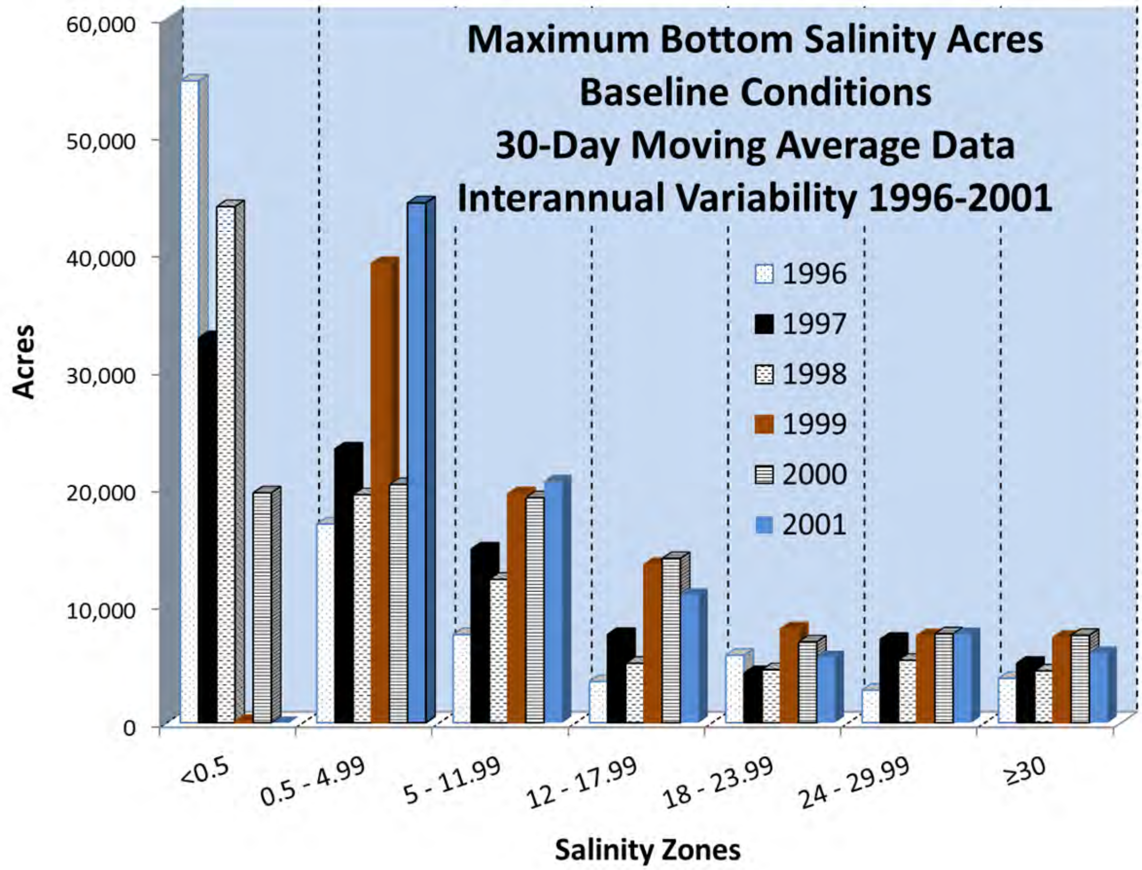

Figure 6.2 Inter-annual Variability in Salinity Zones for the Baseline Conditions of the Simulation

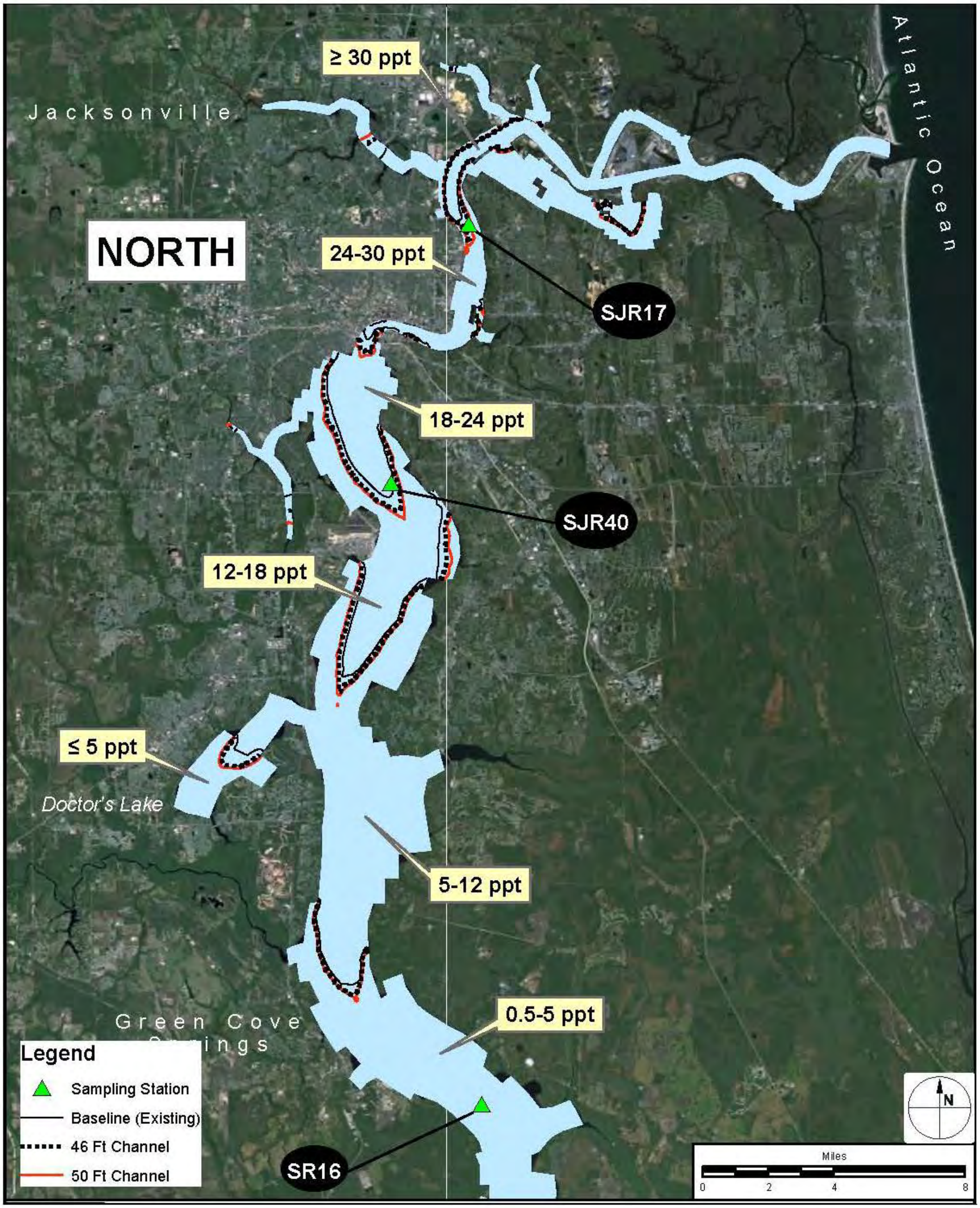

Figure 6.3 Maximum Bottom Salinity, LSJR North, 30-Day Moving Average, Baseline, 46-ft and 50-ft Channels

Figure 6.4 Maximum Bottom Salinity, LSJR South, 30-Day Moving Average, Baseline, 46-ft and 50-ft Channels

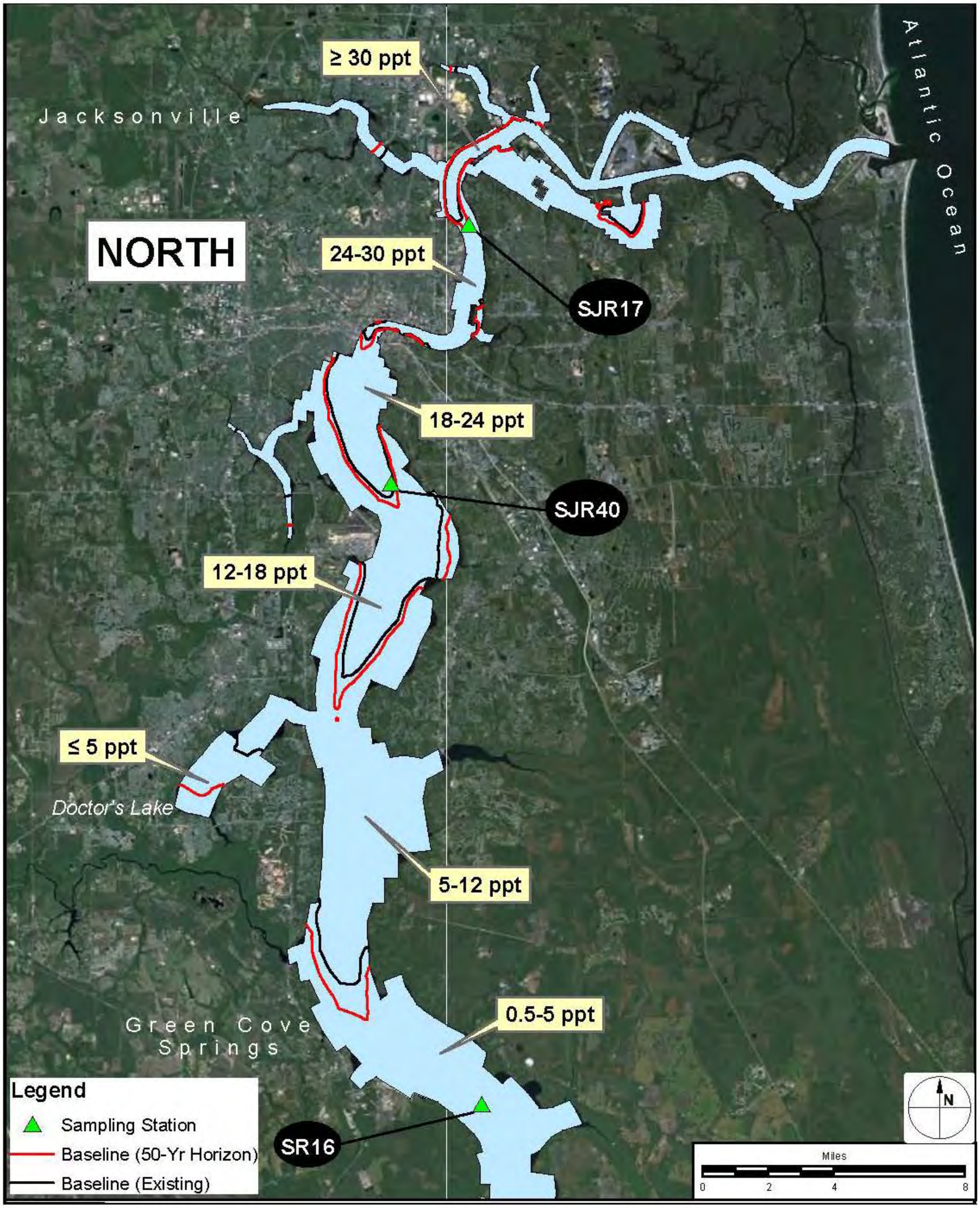

Figure 6.5 Maximum Bottom Salinity, LSJR North, 30-Day Moving Average, Comparison: Baseline and 50-yr Horizon Baseline

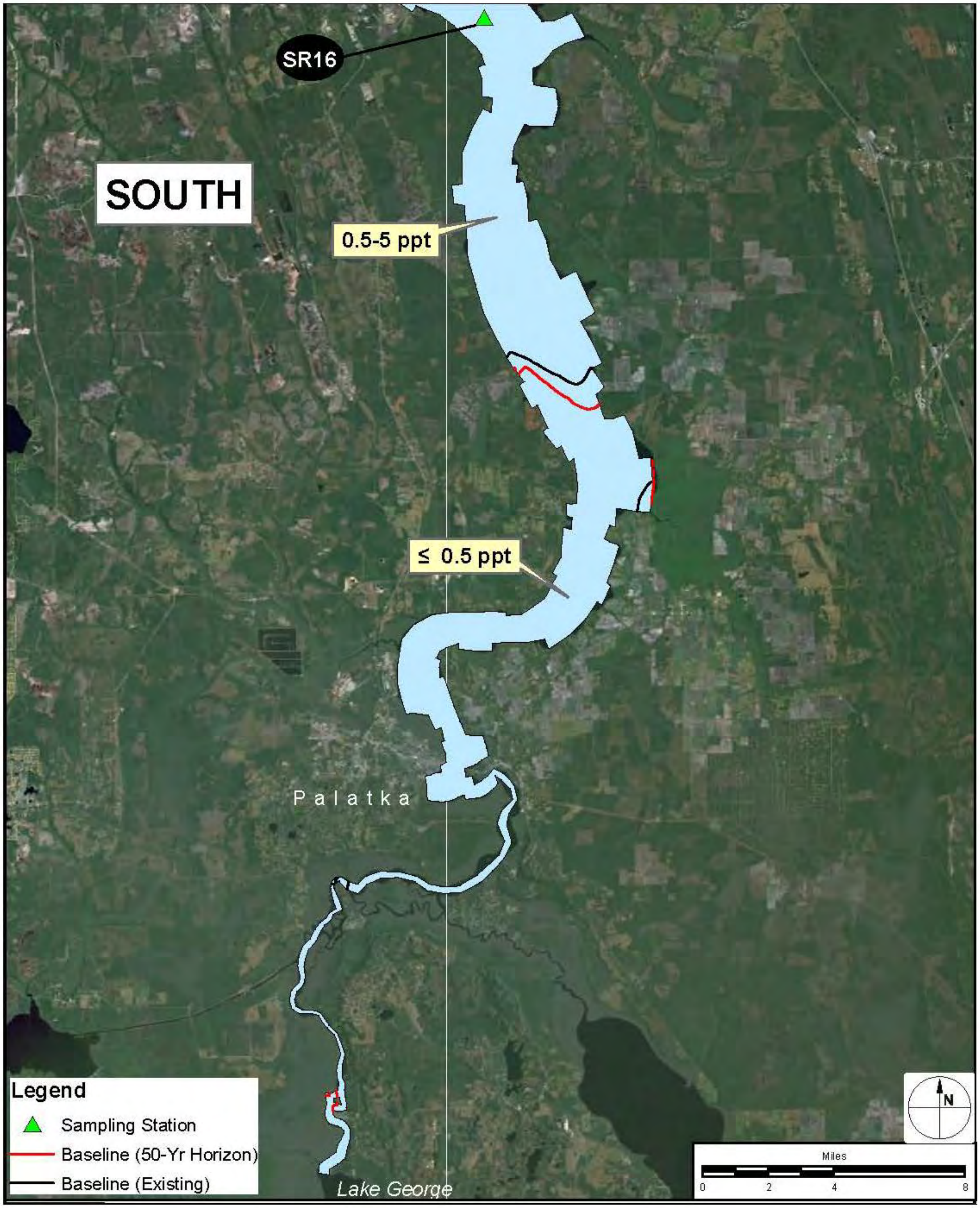

Figure 6.6 Maximum Bottom Salinity, LSJR South, 30-Day Moving Average, Comparison: Baseline and 50-yr Horizon Baseline

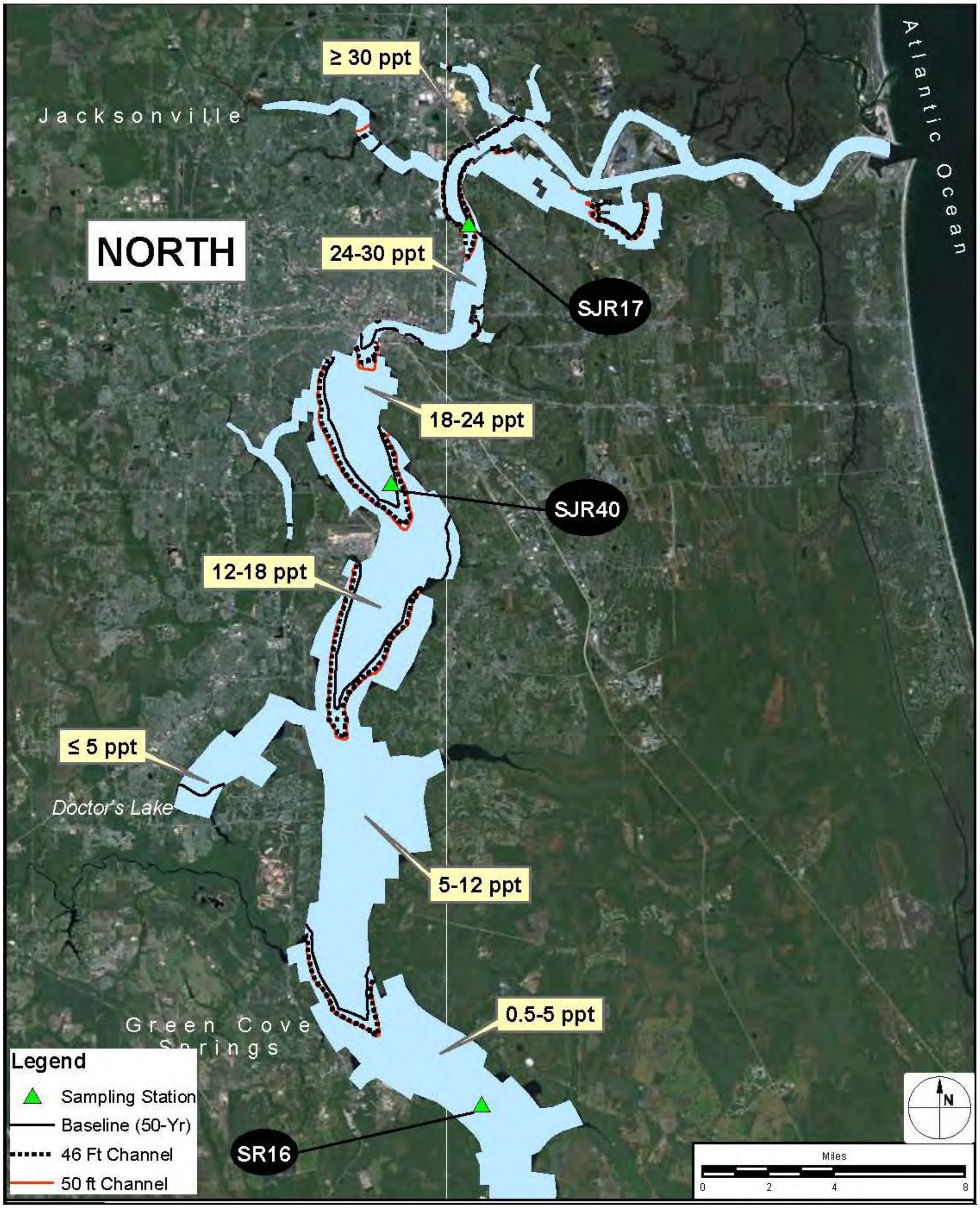

Figure 6.7 Maximum Bottom Salinity, LSJR North, 30-Day Moving Average, 50-yr Horizon: Baseline, 46-ft and 50-ft Channels

Figure 6.8 Maximum Bottom Salinity, LSJR South, 30-Day Moving Average, 50-yr Horizon: Baseline, 46-ft and 50-ft Channels

6.4.2 Changes in Salinity Zone Areas

Each alternative reduces the area of the lowest salinity zone and generally distributes the area lost to the <0.5 ppt zone among the ≥0.5 to <24 ppt salinity zones (Figure 6.9). The ≥24 ppt – <30 ppt zone decreased in all channel deepening alternatives and all deepening alternatives increased the salinity zone ≥30 ppt. The physical structure of the river may explain what occurs in the ≥24 ppt – <30 ppt zone. The river narrows in the baseline ≥24 ppt – <30 ppt zone and the bottom shifts from relatively deep (> 30 ft deep) to a much more shallow condition (≤15 ft deep) near the upstream end of the section. This rapid elevation change and the narrowness of the river in that area may tend to minimize change in the middle of the ≥24 ppt – <30 ppt zone and the narrowness of the river may restrict mixing (and thus salinity changes) in that area compared to conditions at the upstream and downstream of that section of the river. The most dramatic percent increases in the 50-year horizon areas of the most saline bottom conditions occur in the downstream end of the river with salinities ≥30 ppt (Figure 6.9).

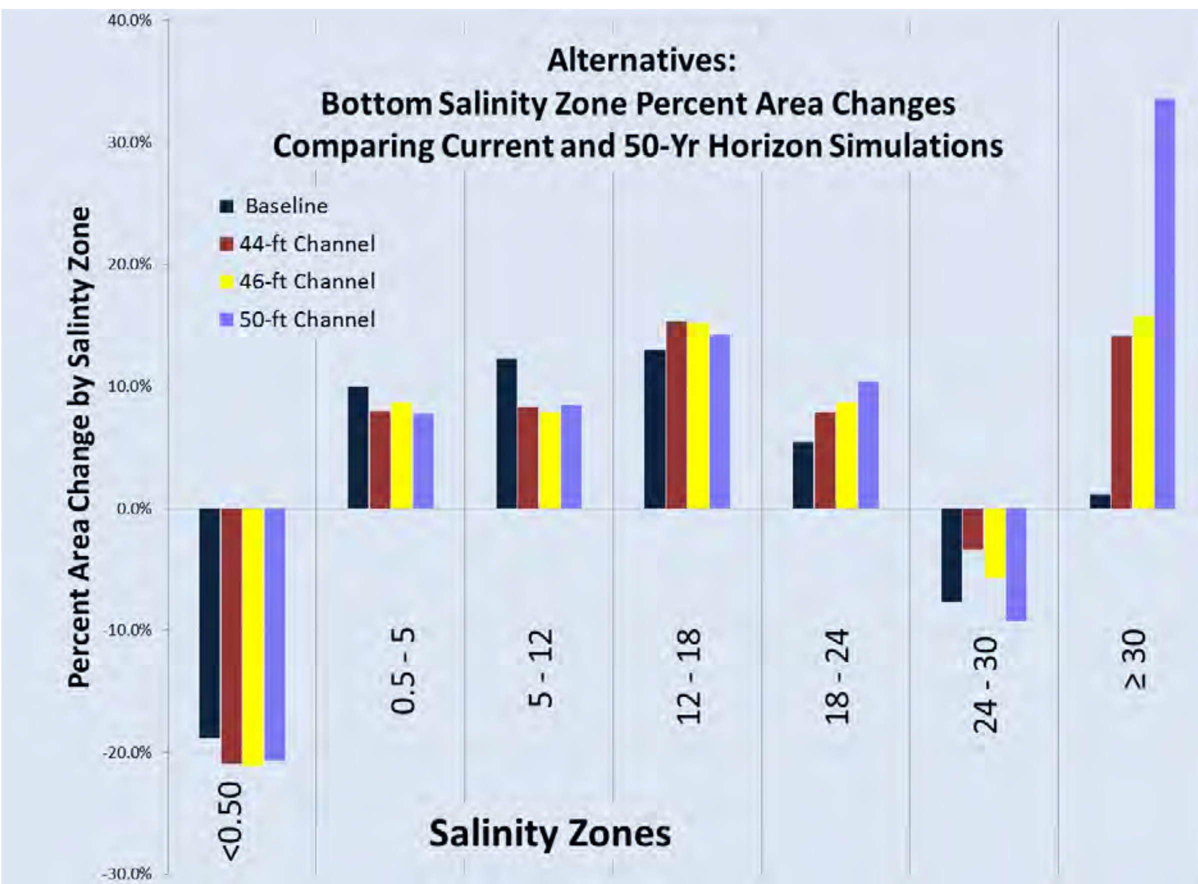

Figure 6.9 Average Salinity Zone Percent Changes Comparing the Current Baseline to Each Alternative Considered at the 50-yr Horizon

6.4.3 Changes in BMI Densities

A spreadsheet model of Equation 1 constructed by SJRWMD (Edgar Lowe, personal communication April 6, 2012), used the changes in area of each salinity zone with respect to the baseline area to calculate total BMI density changes by deepening alternative. The model calculated the percent change in area of a zone (negative or positive) multiplied by the baseline population density for that salinity range. The spreadsheet could also calculate total abundance of a salinity zone; as these calculations simply reflected the abundance changes as the new density times the change in area, this study does not report abundances.

Because changes in area formed the basis for changes in BMI density, only minor density changes occurred between alternatives and between current and 50-yr horizon conditions. The greatest density changes occurred along the estuary salinity gradient. Densities in the freshest portions of the project area averaged over 6,000 individuals / m^2. Moving toward the river mouth, densities fell by about 25% between the freshest zone and salinities of 0.5 ppt to 5 ppt. Densities fell by almost 50% after salinity increased above 5 ppt, and fell between about 30 and 40% with succeeding salinity zones up to 24 ppt. The two most saline zones had very similar densities (between about 500 and 700 individuals / m^2 (Figure 6.10).

Only relatively small maximum bottom salinity zone shifts in the river occurred due to deepening alternatives (Figures 6.4 and 6.5) ft to the effects of the 50-ft channel alternative (Figure 6.5) show that the most extreme change shifts the salinity zones relatively little. The figure shows the differences between the baseline and the deepest channel alternative salinity values for the maximum 30d moving average day values in the 1999 simulation. 1999 was chosen because it is the first very dry year of the simulation period.

6.4.4 Partial Duration Frequency Analysis of Salinity Behaviors

Comparisons of salinity level durations at three points in the river (Figure 6.1: SJR17, SJR40, SR16) for alternative simulations provided another way to consider potential impacts of channel deepening on the BMI community. Comparisons of partial duration frequency analysis results (PDFA) for maximum 30d moving average bottom salinity demonstrates the differences in bottom salinity maxima at different locations and showed where salinity durations did not change.

The bottom layer of one simulation model cell provided the data for PDFA analysis of each of the three locations shown in Figure 6.1. The point farthest downstream, SJRMWD Station ID SJR17 showed little change in 30 ppt and 24 ppt salinity duration curves (Figures 6.11 and 6.12). The 50-yr Horizon 50-ft Channel alternative showed some increase in duration for low probability events

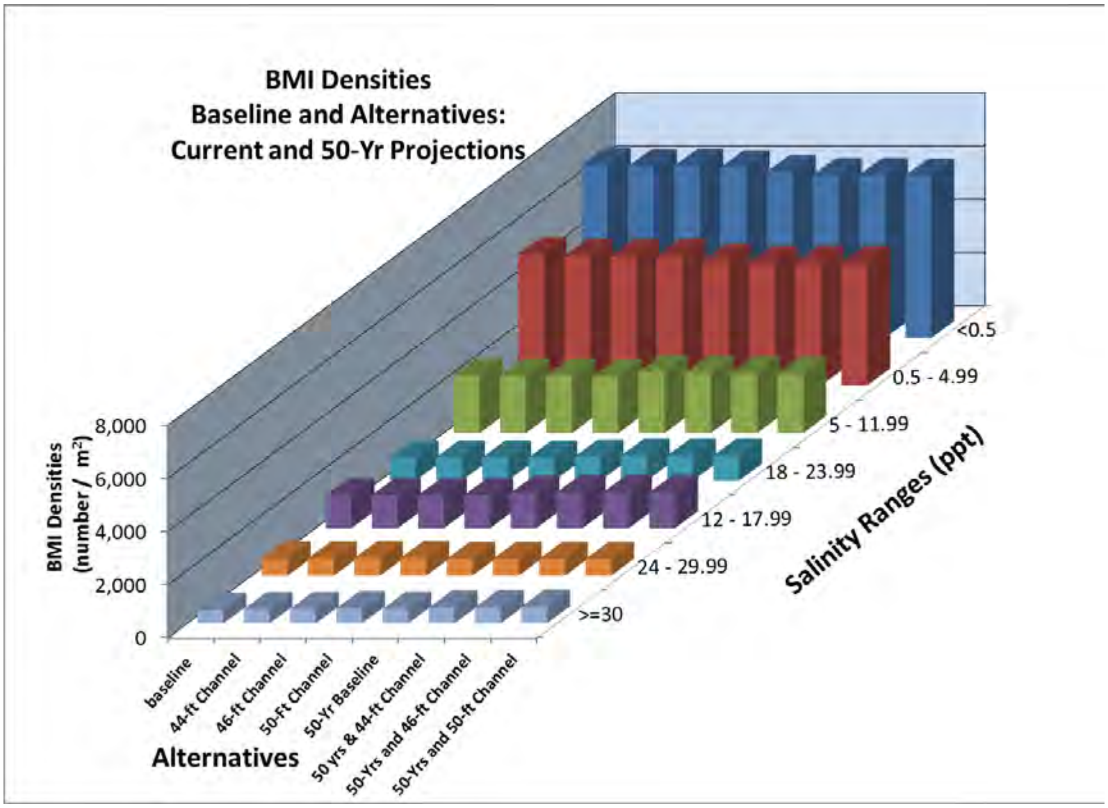

Figure 6.10 Total BMI Densities for Baseline and Alternative Current Condition Simulations and 50-Yr Horizon Condition Simulations

At SJR17, Channel deepening alternatives did not affect salinity duration probabilities at the 30 ppt and 24 ppt salinity breaks (Figures 6.11 and 6.12). Deepening begins to affect duration of salinity events at 18 ppt (Figure 6.13, 6.14). Channel deepening increases the probability of relatively long-duration (50 – 350 d) salinity events 5% to 10% above the baseline condition. All "long-duration" events probabilities are relatively low (below 20% annual probability of occurrence). The simulations provided similar results for this site under the 50-yr horizon condition. At 12 ppt however, the 50-ft Channel alternative (both under current and 50-year horizon conditions caused clear changes in 12 ppt salinity events (Figure 6.15) with probabilities of between 15% and 30% changes of one year or longer increases in salinities compared to the baseline condition. The project did not appear to greatly affect tested salinity regimes lower than 12 ppt at SJR17.

Changes to salinity regimes at SJR40 (Figure 6.1) do not become apparent until the 1 ppt salinity level (Figure 6.16, 6.17, 6.18). At 5 ppt, all duration frequencies lie atop on another. At 1 ppt, Figure 5-15) each alternative has a distinct probability pattern, with changes beginning at low duration events with close to 40% annual probability. The several alternatives produce very distinct differences for events with 20% probabilities or less at durations of 50 or more days annually. The increase in event probability increases in regular order from baseline to 50-ft alternative, with 50-yr horizon conditions showing greater change than alternatives under current conditions. The differences span about 15% points all with less than 20% probability. At this location, the 0.5 ppt event salinity duration patterns (Figure 6-16) are very similar to the 1 ppt events. The 50-yr horizon 50-ft channel alternative increases salinity events more distinctly than do the other alternatives or the other alternatives compared to the baseline.

At the SR16 location, the upstream-most station of the three tested (Figure 6.1) some unusual salinity dynamics occur. At 5 ppt, the maximum salinity for which the baseline and deepened channel alternatives differ greatly, the baseline condition salinity duration probabilities are in reverse order for the 50-year horizon. This means that the baseline 50-yr horizon condition has the greatest durations at any particular probability, and the 44-ft alternative next in those terms, followed by the 46-ft and 50-ft alternatives in that order (Figure 6.19). A possible hydrodynamic reason for this occurs, if at this location in the river for these alternatives, the ebb tide is stronger (moves downstream more rapidly) for the alternatives than does the baseline condition. Therefore, salinity would tend to mix less and remain higher for longer periods for the baseline condition than for the channel deepening conditions.

Figures 6.20 through 6.24, display PDFA results for 4 ppt, 3 ppt, 2 ppt, 1 ppt, and 0.5 ppt salinities. The series shows the effects of this reversal shifting back to an expected pattern between 4 ppt and effects of channel alternatives at SR16, located most upstream of the three sites tested (Figure 6.1) occurred between 0.5 ppt and 2 ppt salinity. At 0.5 ppt salinity, the 50-ft horizon differences differentiate themselves clearly from the current condition set of alternatives, with greater probabilities of 0.5 ppt salinity events between 30 and 200 days.

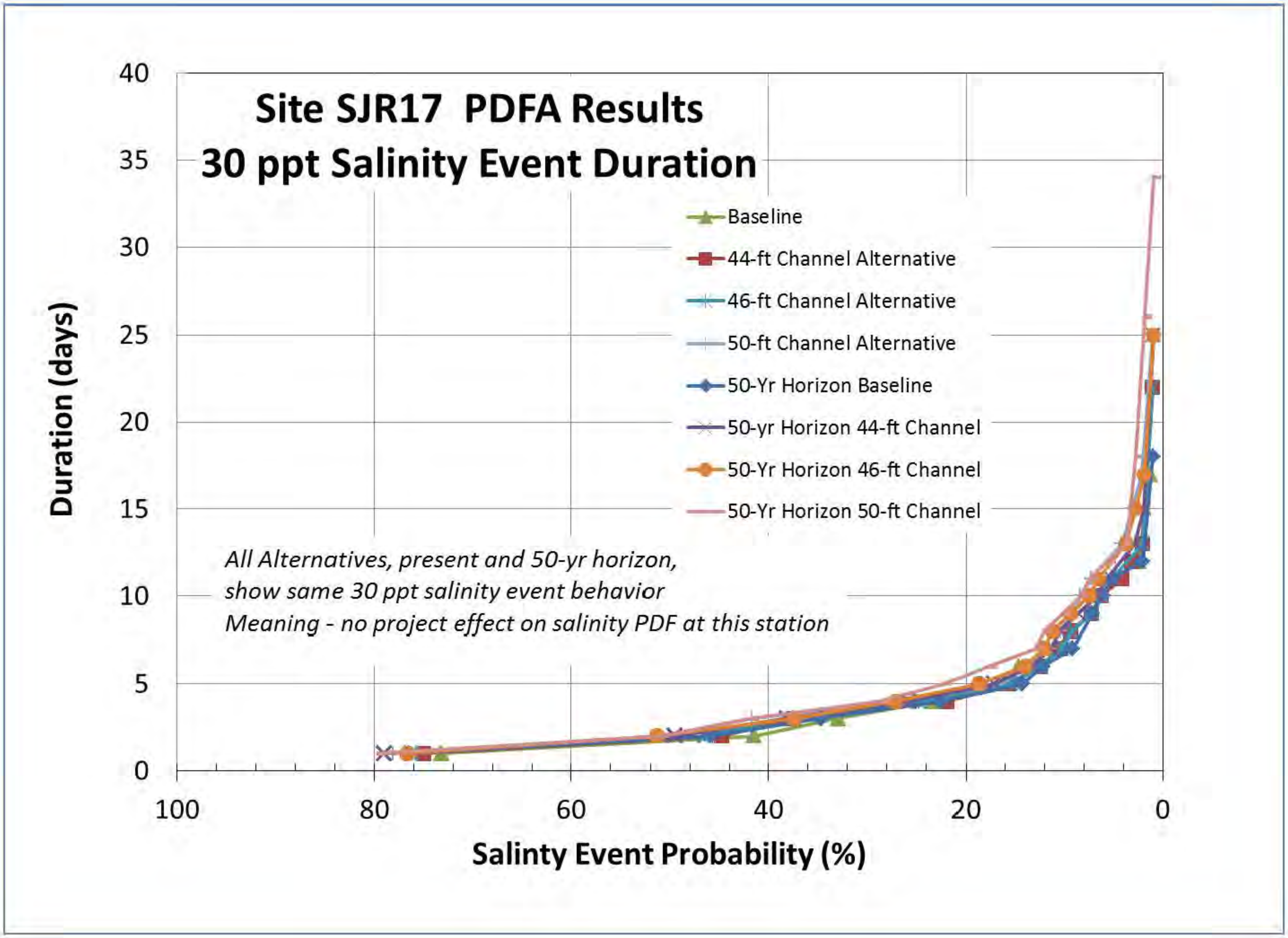

Figure 6.11 Partial Duration Frequencies for Current and 50-yr Horizon Project Alternatives: 30ppt Salinity Duration Probabilities at Site SJR17

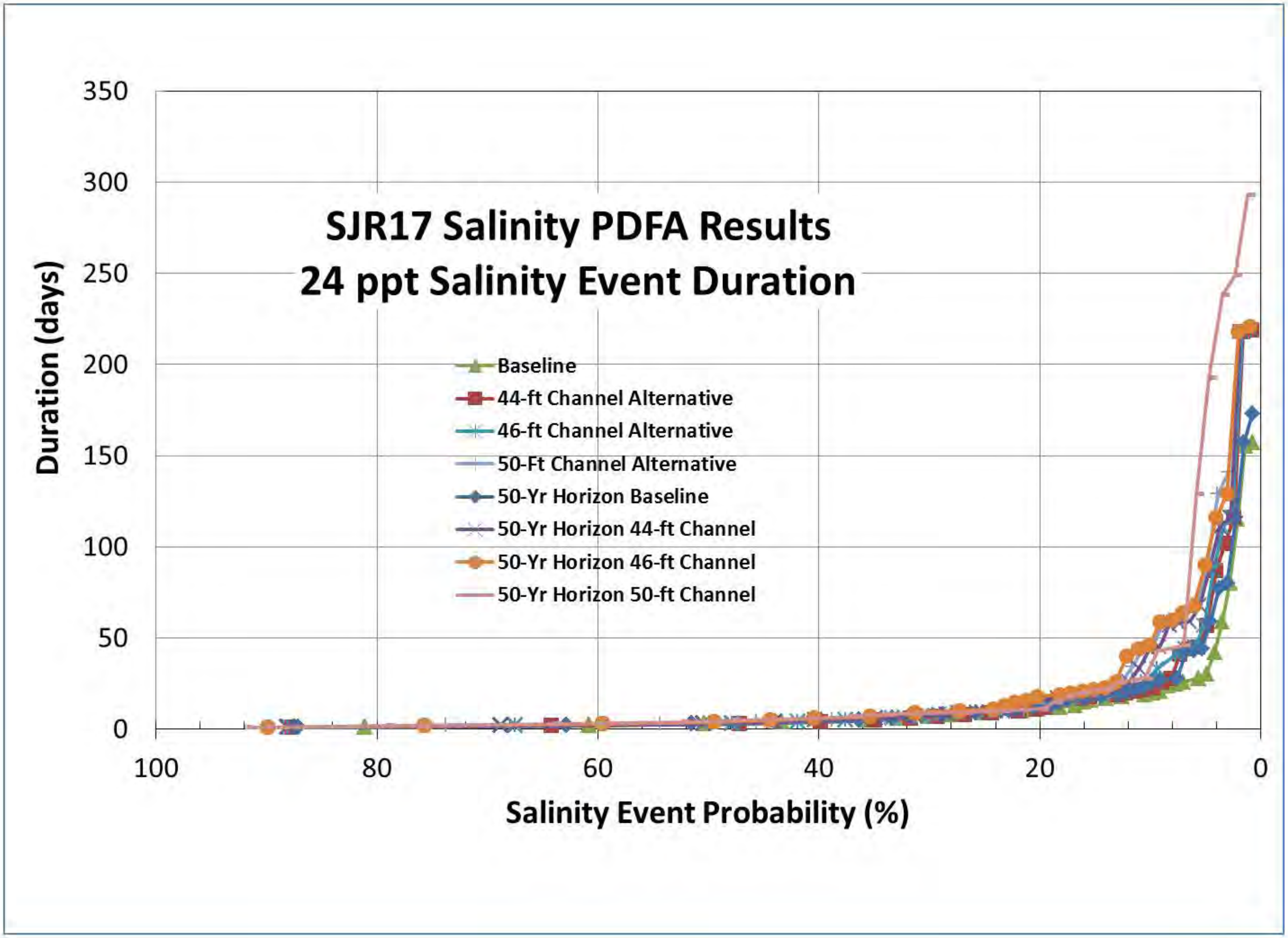

Figure 6.12 Partial Duration Frequencies for Current and 50-yr Horizon Project Alternatives: 24 ppt Salinity Duration Probabilities at Site SJR17

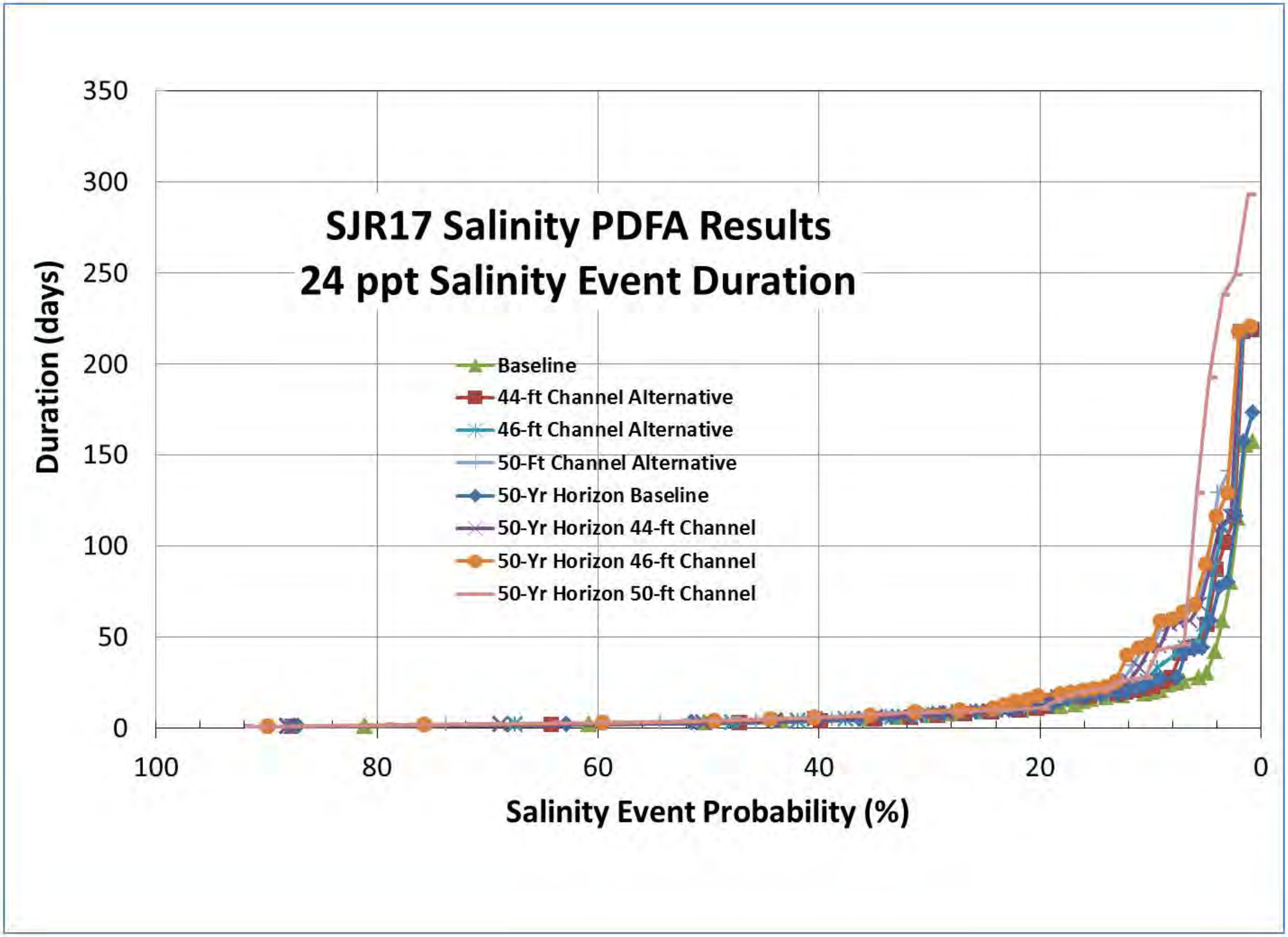

Figure 6.13 Partial Duration Frequencies for Alternatives under Current Conditions: 18 ppt Salinity Duration Probabilities at Site SJR17

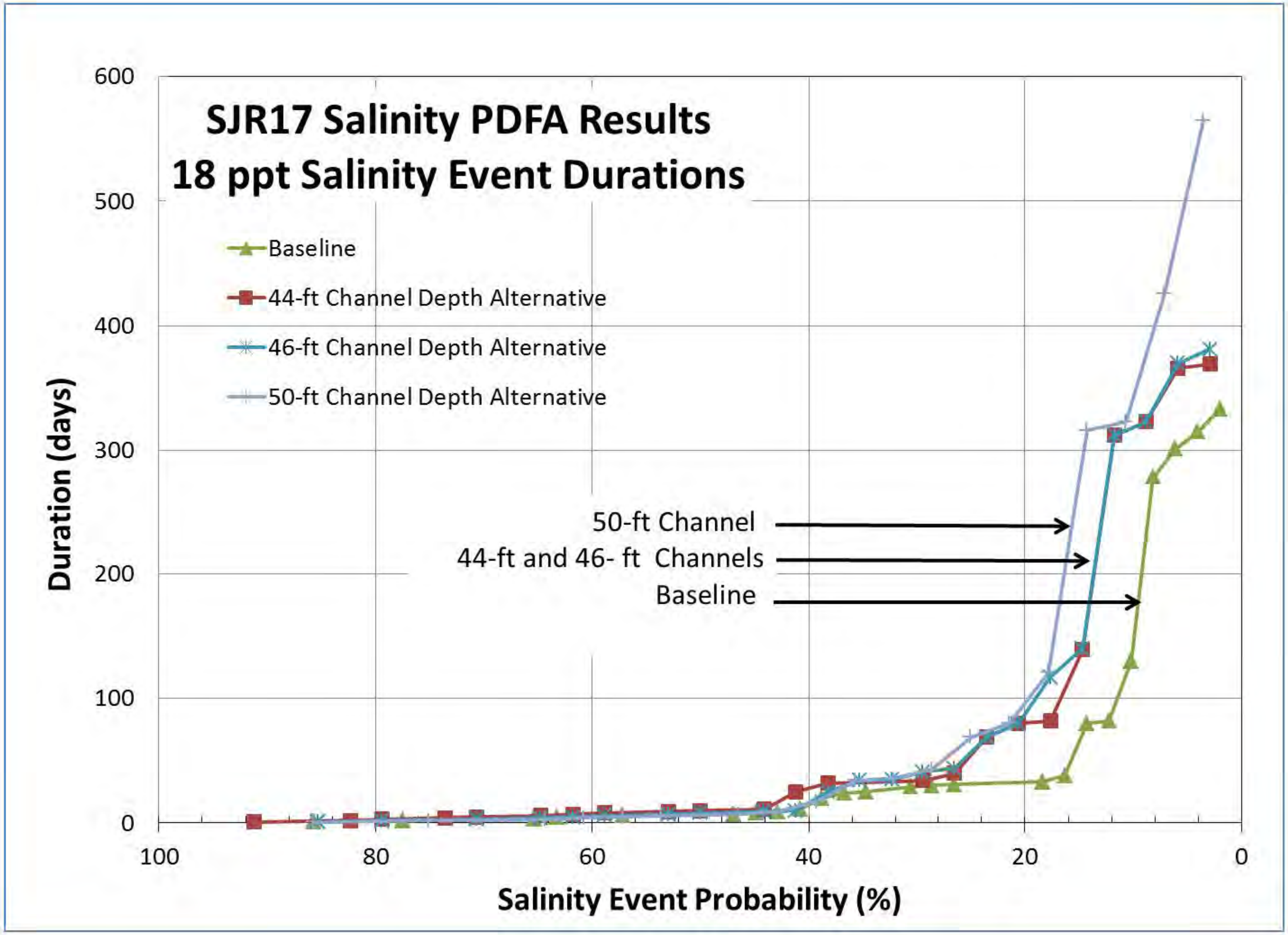

Figure 6.14 Partial Duration Frequencies for the 50-yr Horizon: 18 ppt Salinity Duration Probabilities at Site SJR17

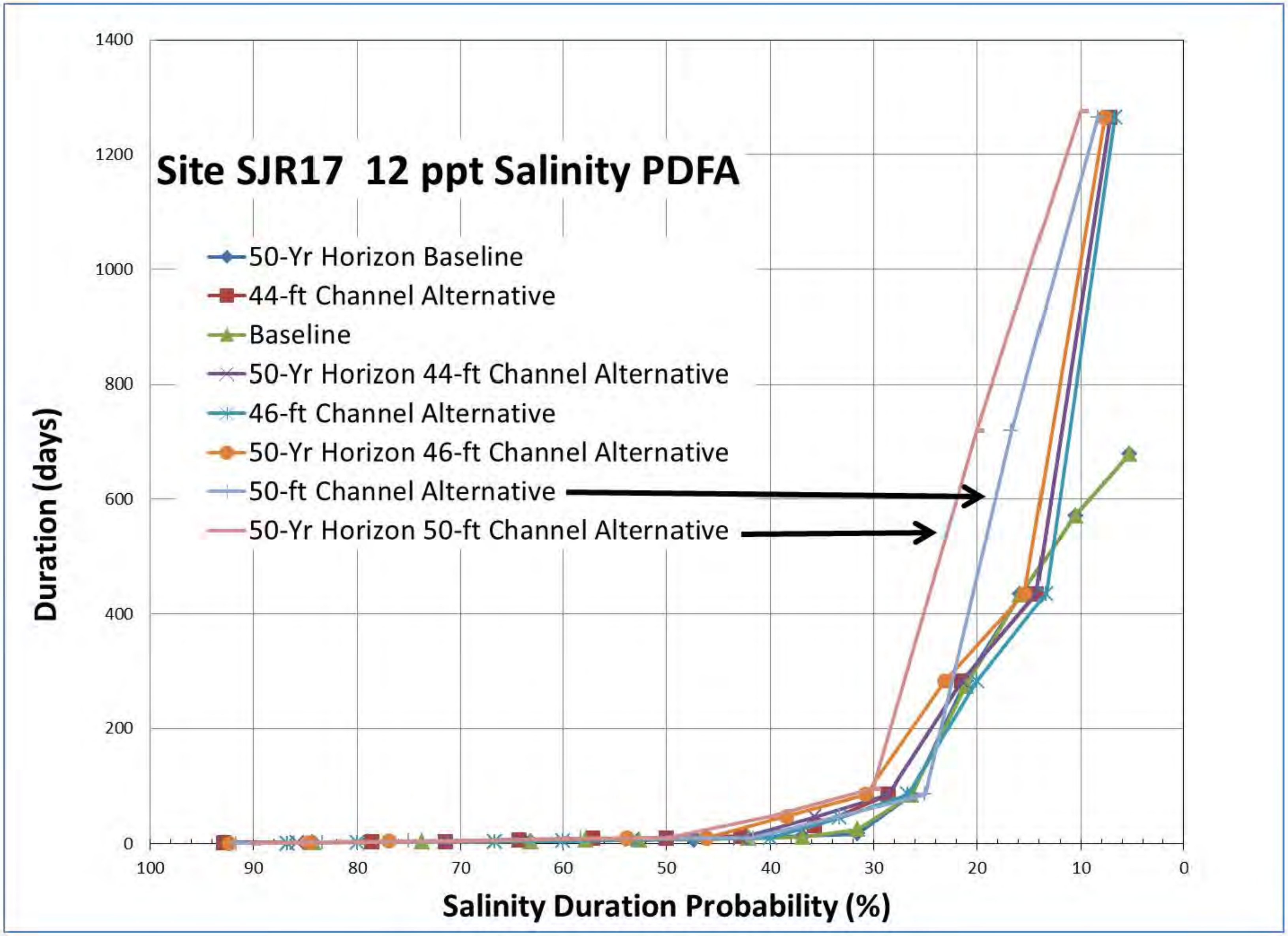

Figure 6.15 Partial Duration Frequencies for Current and 50-yr Horizon Conditions: 12 ppt Salinity Duration Probabilities at Site SJR17

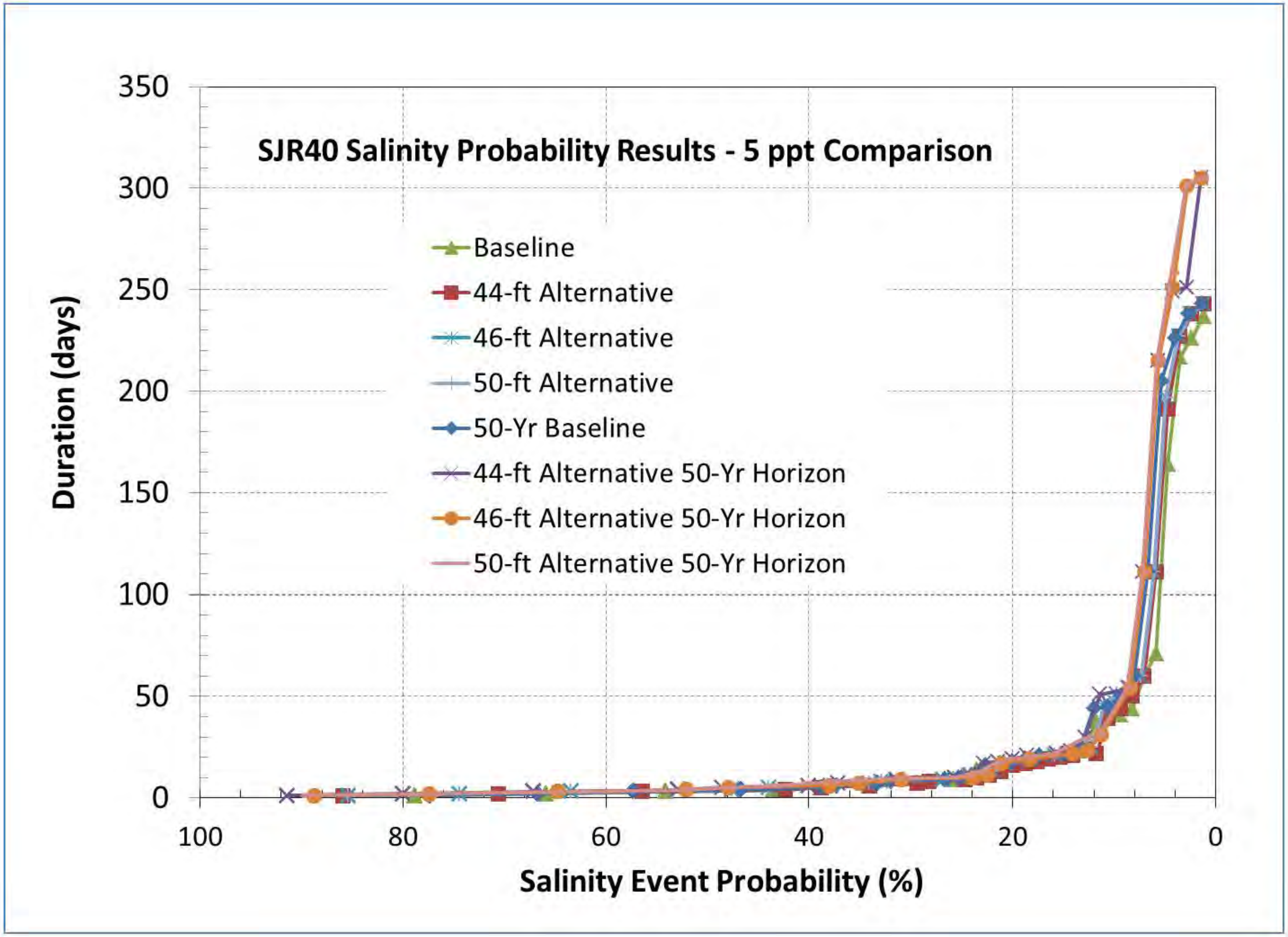

Figure 6.16 Partial Duration Frequencies for Current and 50-yr Horizon Conditions: 12 ppt Salinity Duration Probabilities at Site SJR17

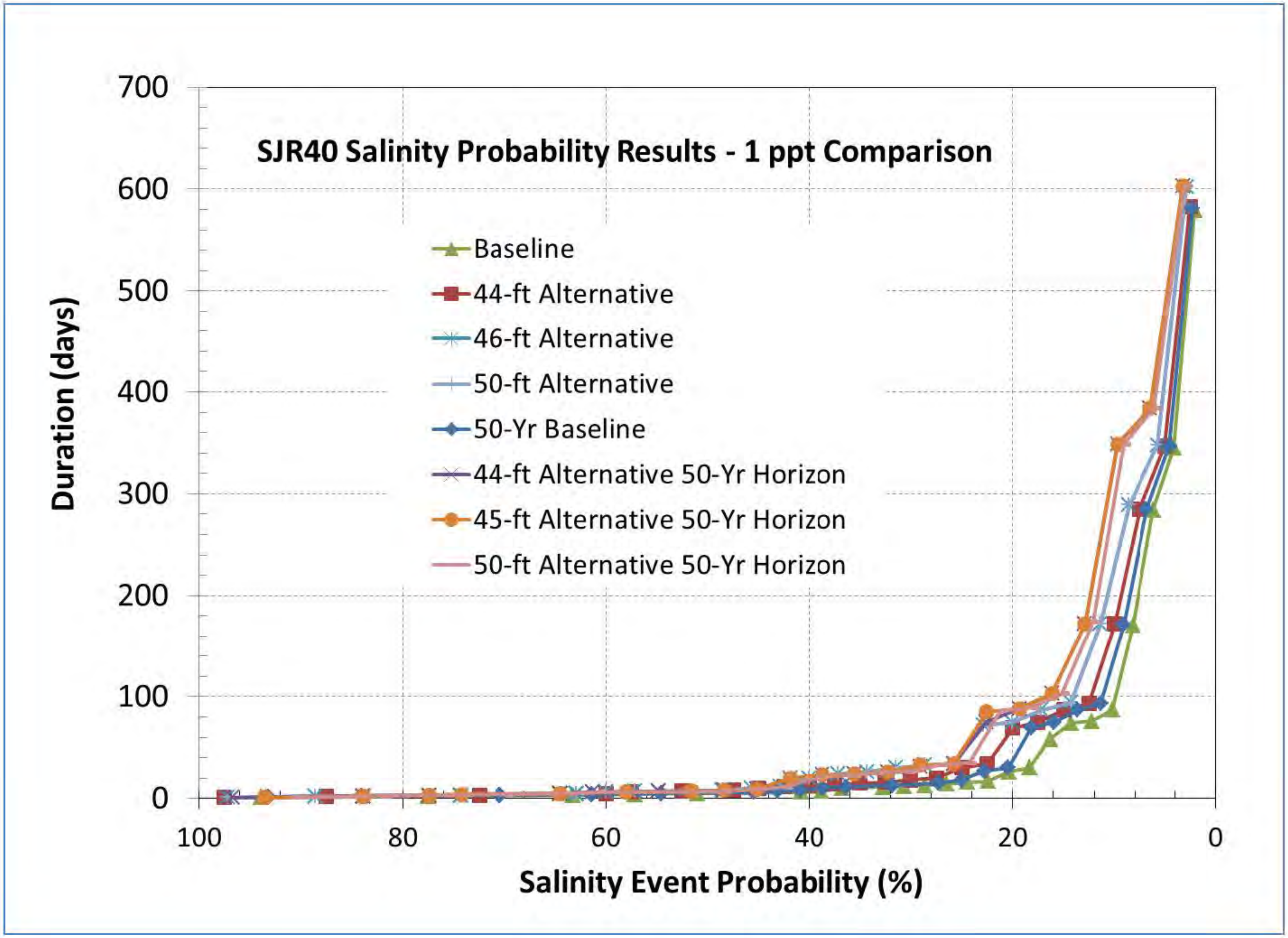

Figure 6.17 Partial Duration Frequencies for 1 ppt Salinity at SJR 40.

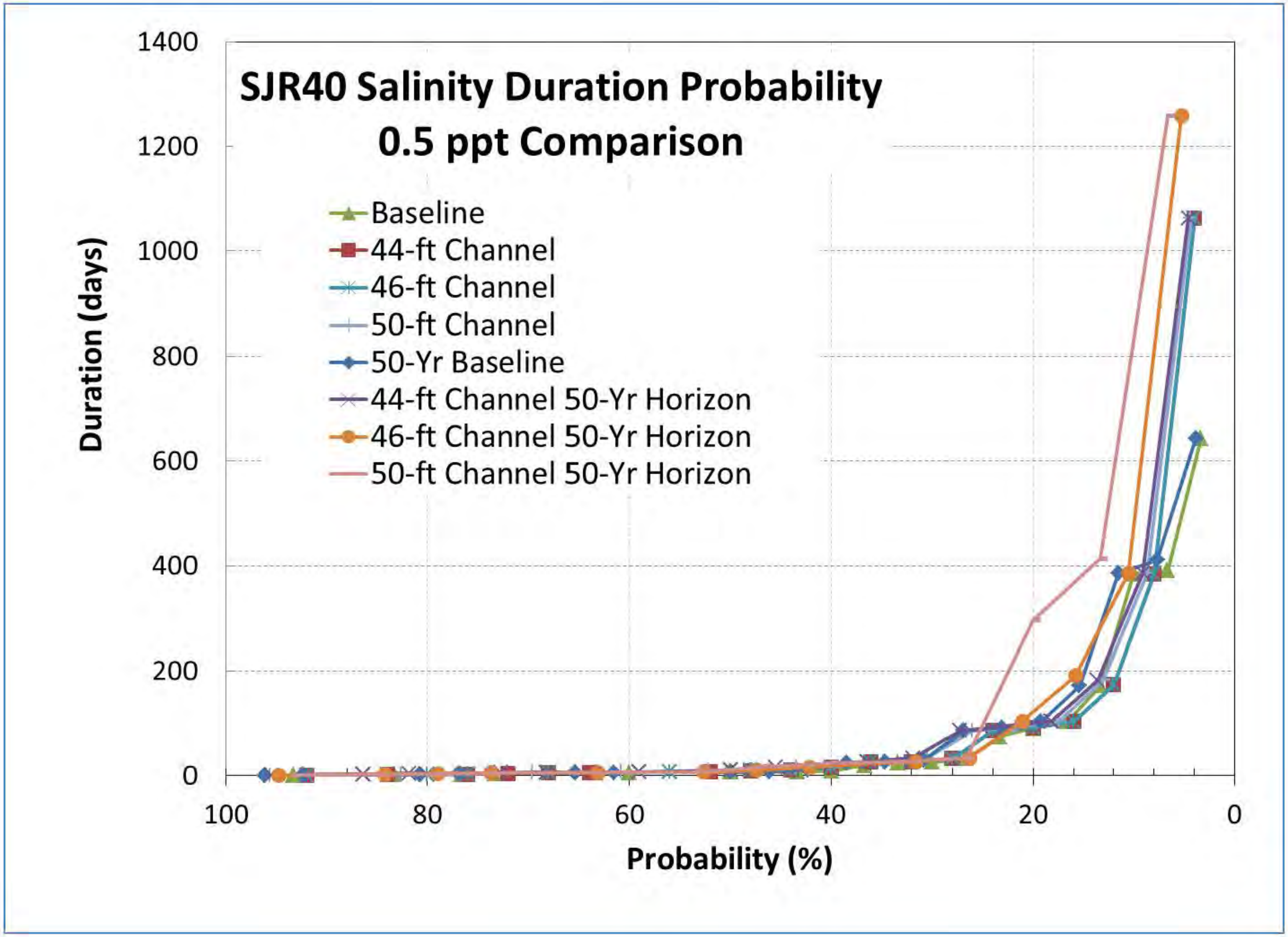

Figure 6.18 Partial Duration Frequencies for 0.5 ppt Salinity at SJR 40.

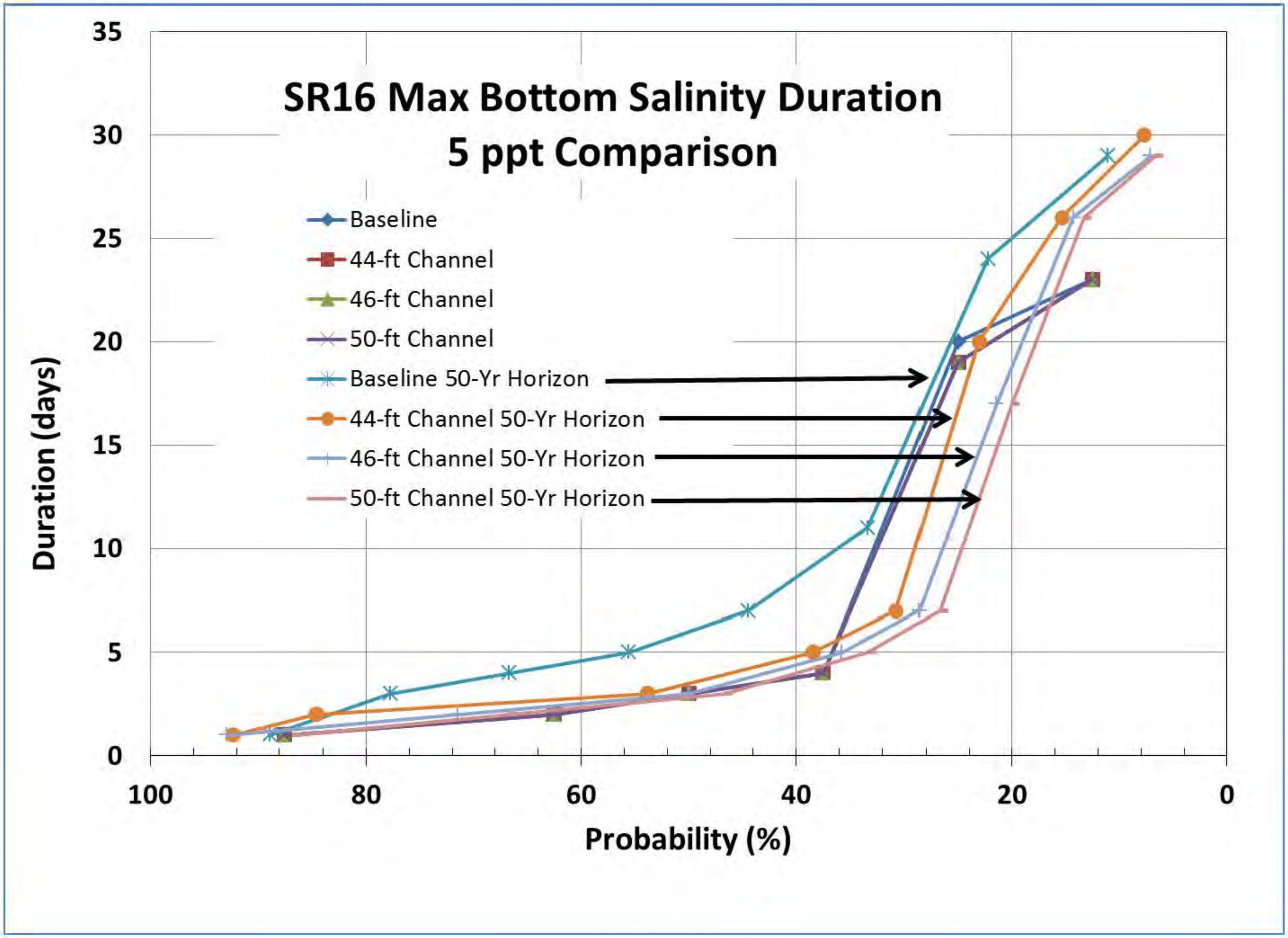

Figure 6.19 Duration Frequencies for 5.0 ppt Salinity at SR16.

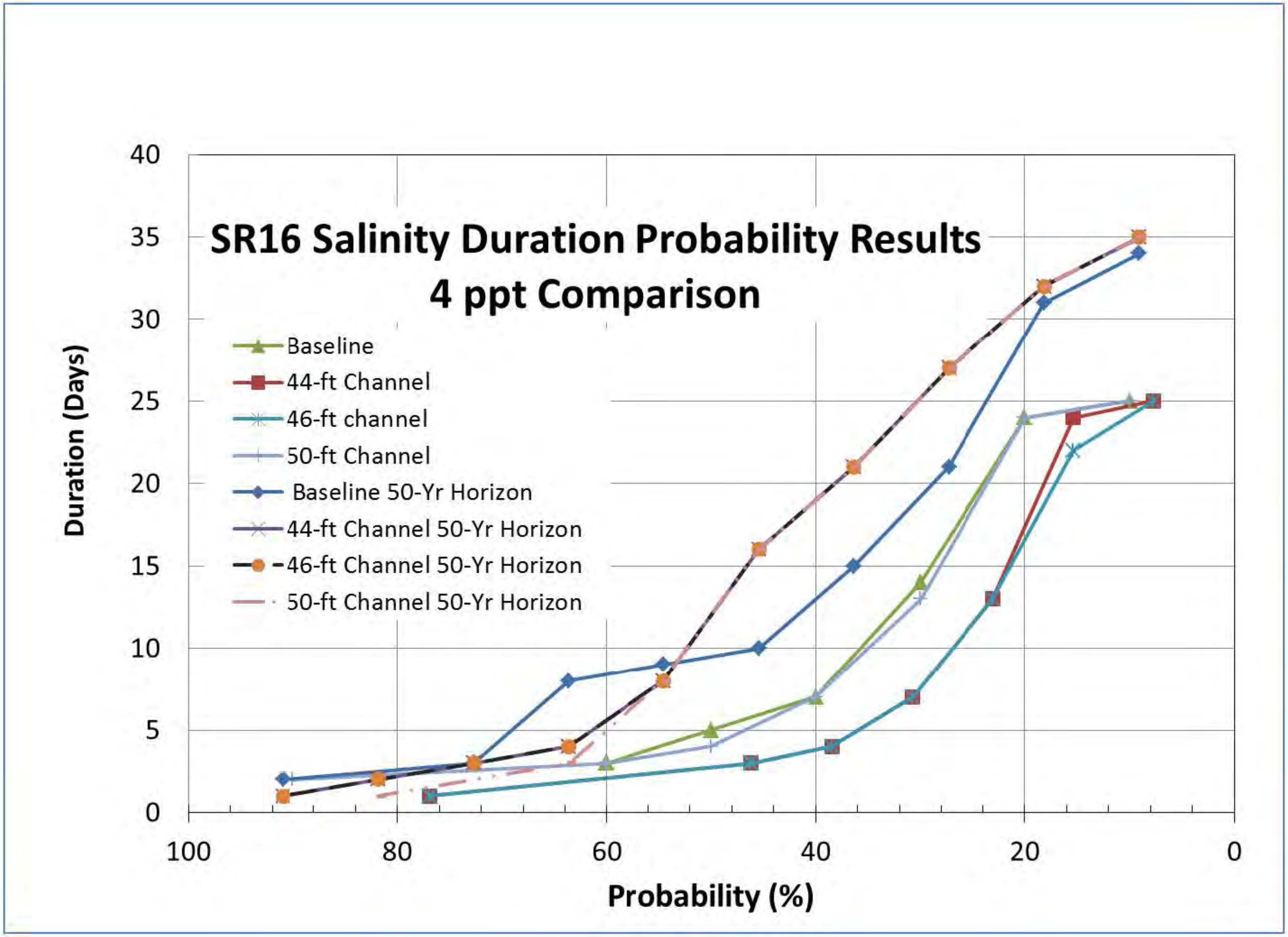

Figure 6.20 Partial Duration Frequencies for 4.0 ppt Salinity at SR16.

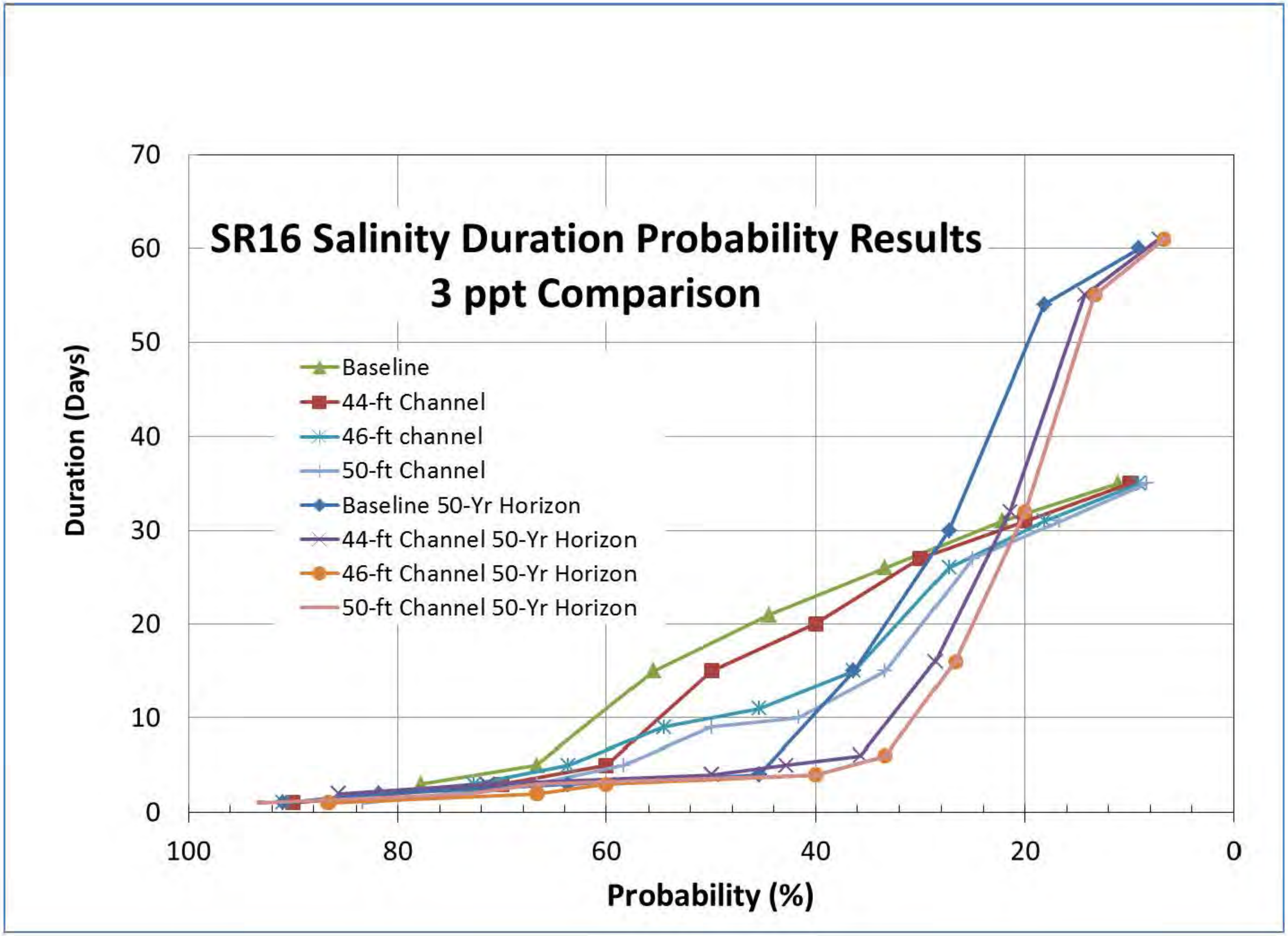

Figure 6.21 Partial Duration Frequencies for 3.0 ppt Salinity at SR16.

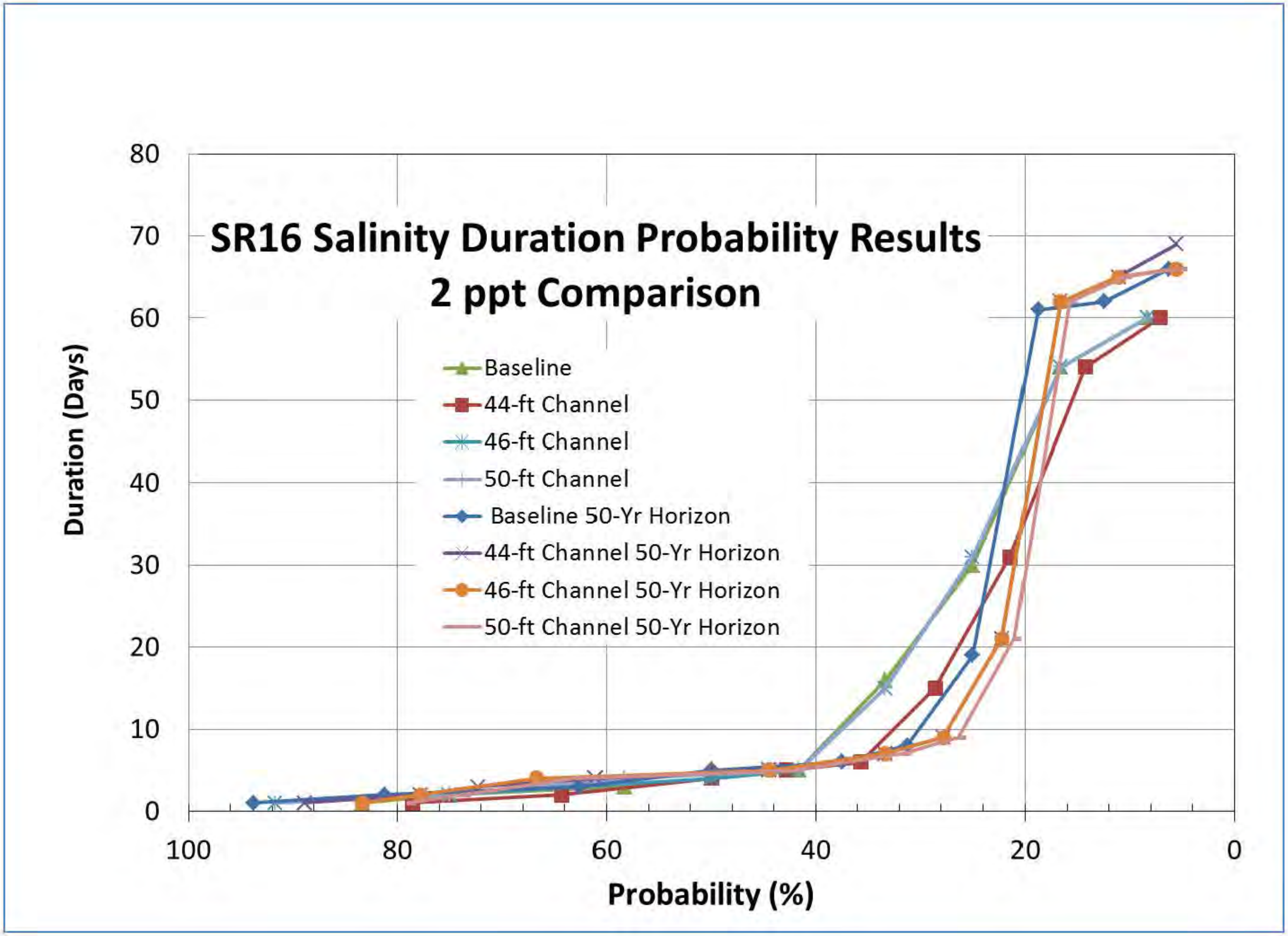

Figure 6.22 Partial Duration Frequencies for 2.0 ppt Salinity at SR16

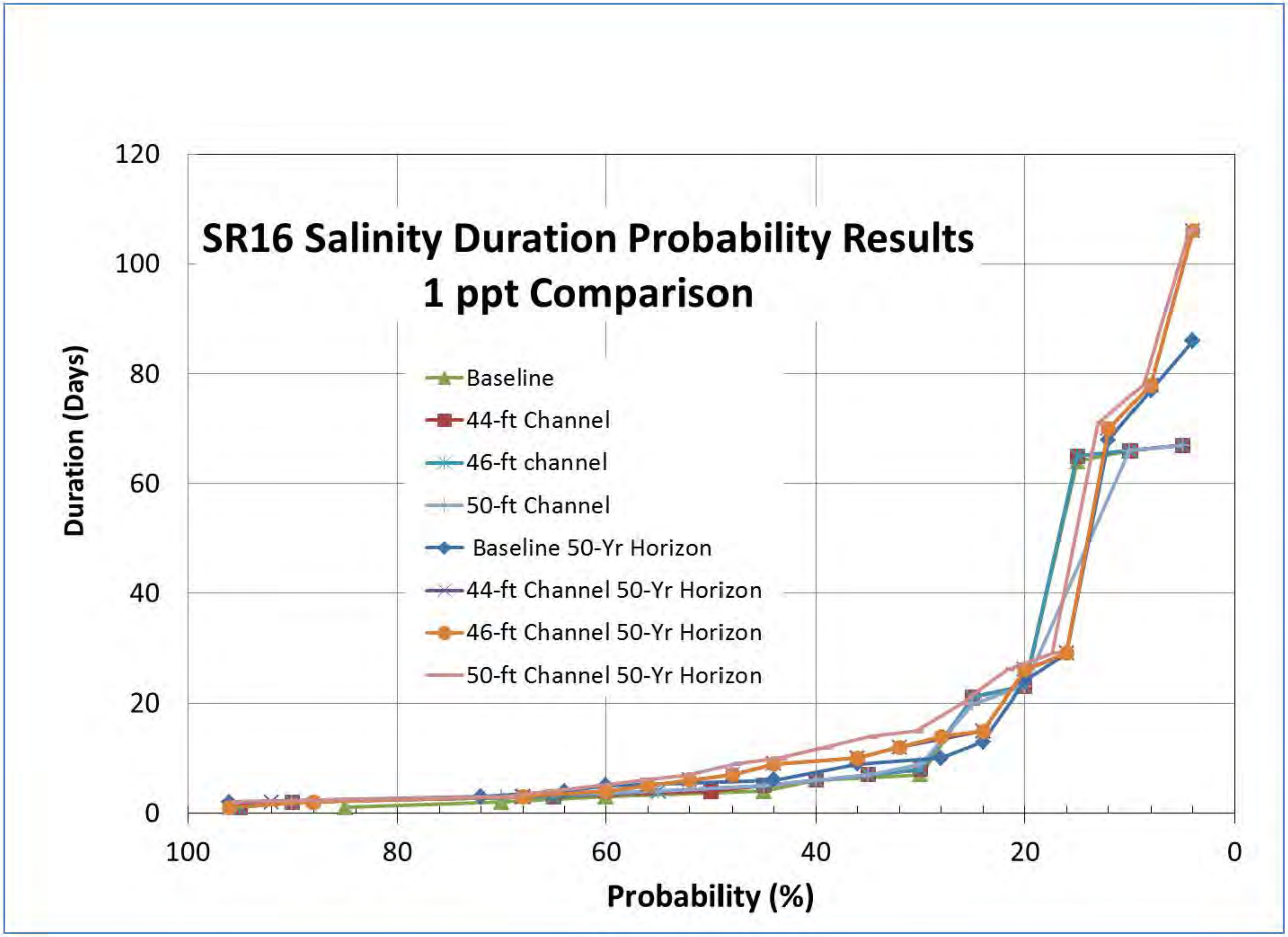

Figure 6.23 Partial Duration Frequencies for 1.0 ppt Salinity at SR16

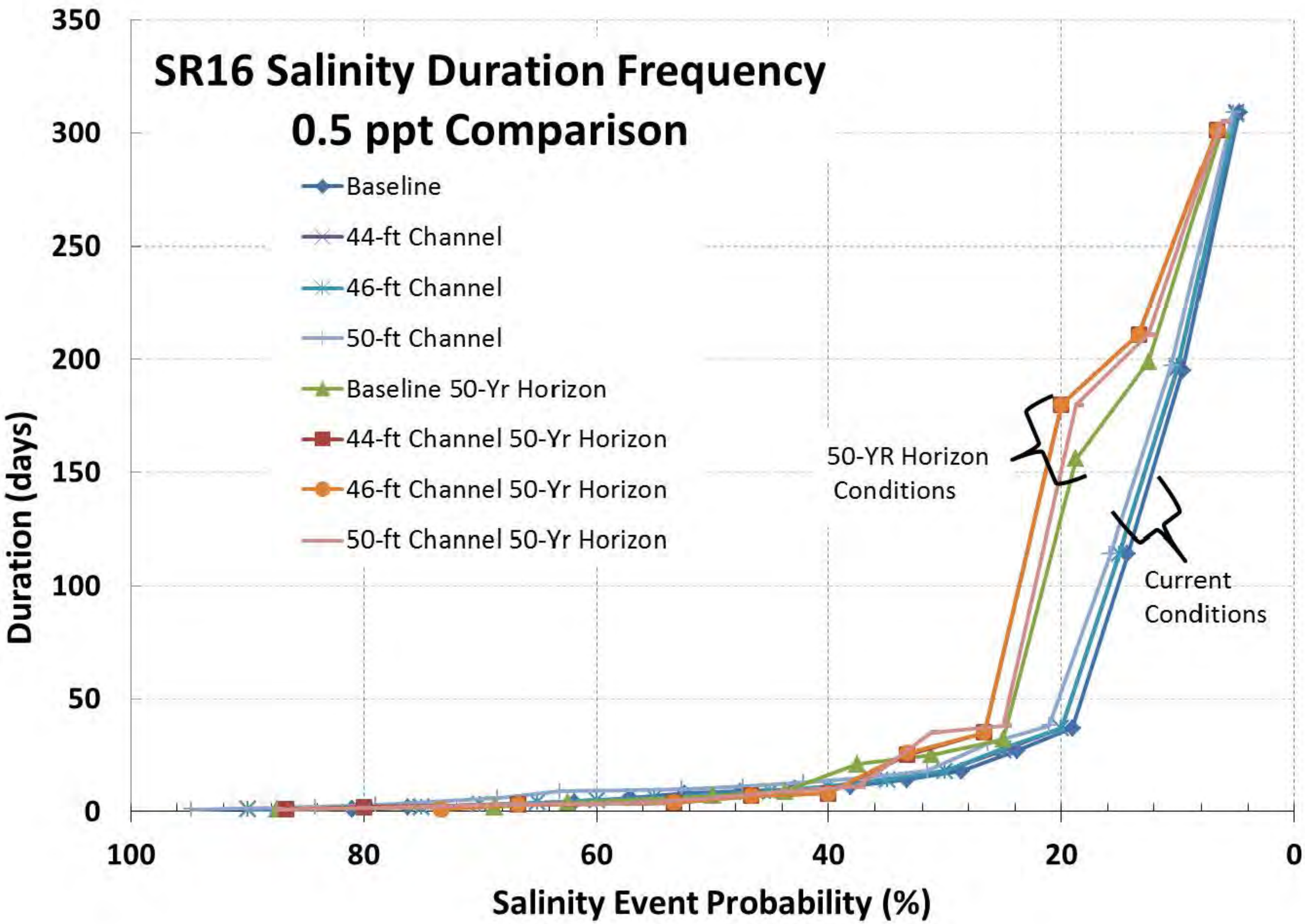

Figure 6.24 Partial Duration Frequencies for 0.50 ppt Salinity at SR16

6.4.5 *Effects of Salinity Changes on Commercially Important Species*

Harvest of blue crab (*Callinectes sapidus*) from the LSJR and shrimp (particularly white shrimp *Litopenaeus setiferus*, but also brown and pink shrimp) from the nearshore Atlantic waters (> one mile from shore by regulatory requirement) provide an important seafood harvest industry for the general project area. The LSJR estuary serves as an important component of the life cycle of these taxa. Consideration of proposed salinity changes on these commercially and recreationally important fisheries should evaluate the potential for channel deepening to affect the life history and production of these species.

Blue crab

The blue crab, *Callinectes sapidus*, has important ecological and economic functions in the LSJR estuary. Ecologically they are scavengers, processing a wide range of food items, including smaller and/or more sedentary prey (e.g., bivalve mollusks) and provide a common prey item in the diets of many estuarine fishes (Van Den Avyle and Fowler 1984). Blue crabs have provided for a major commercial fishery in the LSJR for decades, but the Florida Atlantic catch generally has been declining since the 1980s, and that statistic is reflected in landings for the five county area including Nassau, Duval, Clay, Putnam, and St. Johns counties (Figure 6.23). The landings of about 800,000 lbs of hardshell crabs, a relatively low landing year, had a value of about $1.04 million (Mattson et al., 2012). The population does undergo large oscillations "often related to extended years of drought when blue crab production is apparently low and wet years when blue crab production is apparently high" (Murphy et al., 2007) (Figure 6.22). Soft-shell crab landings and soft-shell production (by holding crabs in cages until they molt) have become more important in recent years (Figure 6.23) but still only account for a relatively small fraction of overall blue crab landings (http://myfwc.com/research/saltwater/crustaceans-marine-arthropods/blue-crabs/).

Sempsprott (2011) summarized blue crab life history and distribution literature, stating, "there is a strong relationship between blue crab survival and habitat quality," pointing to Apalachee Bay and Suwannee Sound/Waccasassa Bay, which have the highest blue crab production in Florida. These very open bays have large areas of tidal marsh and freshwater inflows that reduce salinities that would otherwise result in salinities more closely reflecting the salinities of the larger gulf waters. Guillory et al. (2001) cited alternation of freshwater flows (closely correlated with salinity) nutrient pollution and pesticide runoff as a major components of declines in south Florida blue crab populations.

Effects of Predicted Changes in Salinity on Blue Crab

Deepening of the Federal navigation channel in the first 14 miles of the river has the potential to affect blue crab populations in two ways: alteration of spatial and temporal salinity patterns and/or alteration of critical habitats (especially SAV) or food resources. Evaluation of the potential for effects also requires consideration of the complex life history of the species, with both planktonic (larval) and benthic (juvenile and adult) phases. Jacoby (2012) provided a detailed review of salinity effects on blue crabs that found literature indicating that many life stages of this crab exhibit a fairly wide degree of salinity tolerance, particularly juvenile and adult crabs, which are the main benthic life stages that occur within the river mouth in the lower river and estuary. Based on this review of the literature, in conjunction with the EFDC model-predicted salinity changes described above, salinity changes due to upstream water withdrawals will be unlikely to have an adverse impact on populations of blue crab in the St. Johns River. Minor upstream advances in salinity regimes do not greatly impact the total area of salinity zones, and upstream of Shands Bridge, the greatest potential channel depth produces only very minor increases in frequency and duration of salinity concentrations. For the 50-yr horizon scenarios, alternative-driven changes are similar in degree to the current condition changes, except that the baseline salinities will have slightly farther upstream.

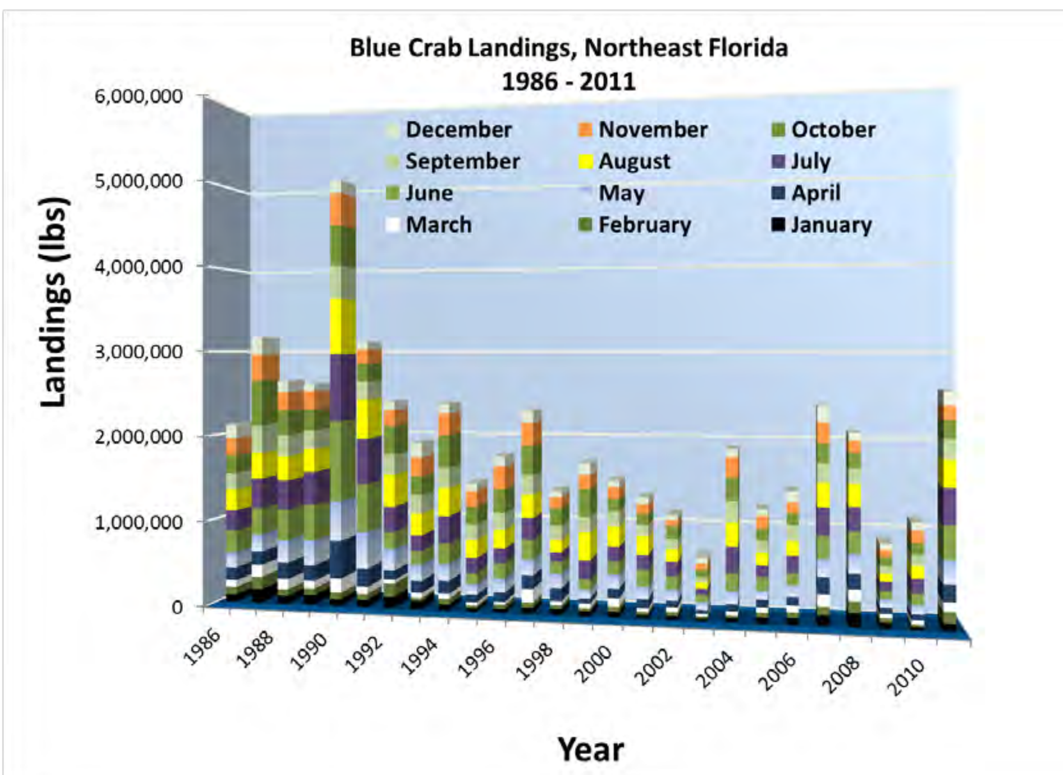

Figure 6.25 Annual Blue Crab Landings from Five Northeast Florida Counties 1986 – 2011

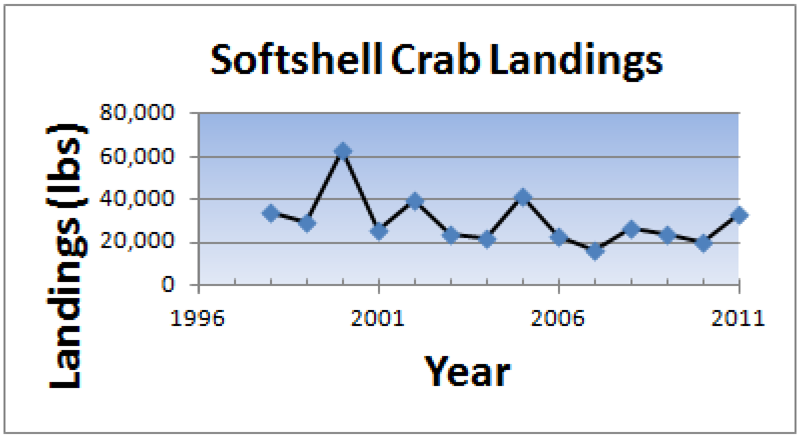

Figure 6.26 Soft-shell Crab Landings 1998 – 2011, for Five-County Northeast Florida Region.

The WSIS study (SJRWMD, 2012: Mattson et al., 2012) evaluated the effects of water withdrawals in the middle and upper St. Johns River on the lower river and estuary. Mattson et al. (2012) concluded that for the "worst case" (greatest upstream withdrawal) scenario, blue crab abundance would increase. The WSIS analysis reaches conclusions opposite to other findings (see above) that extended drought periods (where less water flows down to the estuary) are correlated with decreased crab abundance. Mattson et al. also found that "increased freshwater inflows to the St. Johns River estuary (from the USJRB Projects and 2030 land use) result in reduced blue crab abundance…possibly due to downstream movement of areas of preferred salinity into areas of less-than-desirable habitat (downtown Jacksonville and the Port of Jacksonville). Imposition of withdrawals on these future conditions results in increased crab abundance (Table 4.16)." This conclusion counters findings of crab abundance analyses reported in Sempsrott (2011) and Murphy et al. (2007), where upstream, low salinity conditions are important for female crab reproductive processes, high salinity habitats are sought by juveniles and males, and high inflows are correlated with greater crab abundance in the Florida estuaries studied.

Impacts to SAV habitat from channel deepening (due to increased salinities) appears minor (Chapter 3), and the loss of habitat would not likely impact blue crab populations. The PDFA results for the downstream most site analyzed (SJR17 , above) suggested no changes in salinity regimes at 30 ppt salinity and only minimal changes at 24 ppt salinity, with clear changes due to the deepening alternatives at 18 ppt in that location. These results suggest that the marshes at the mouth of the river would experience only minor shifts in salinity events, maintaining the quality of those marshes, at least with respect to salinity regimes. The findings concerning changes in salinity regimes also suggests that the prey items for the blue crab would not greatly change either. Given the plasticity of the blue crab diet, it appears that small episodic salinity changes would not likely impact the species abundance or biomass production.

Shrimp

White shrimp (*Litopenaeus setiferus*), brown shrimp (*Farfantepenaeus aztecus*), and pink shrimp (*Farfantepenaeus duorarum*) occur in the lower St. Johns River estuary. Of the three, white shrimp are by far the most abundant of the three in commercial landings, followed by brown shrimp and pink shrimp. These shrimp are generally abundant. As consumers of detrital material these species link primary and secondary production by their role as a major food item for many estuarine fishes (mostly sciaenids (e.g., red and black drum, spotted sea trout, croaker), which are also a target of recreational anglers.

Jacoby (2012) provides an overview of the distribution, life history, and ecology of the three penaeid shrimp species and detailed discussion of habitat preferences including (among others) sediment, vegetation, and salinity. He noted that the three shrimp species in nauplii through postlarval stages are tolerant of a wide range of salinities and salinity with optima near marine conditions. Laboratory experiments have shown that larvae can be successfully reared at a range of salinities between 18 – 34 ppt (Perez-Farfante 1969). Juvenile white shrimp in particular has a salinity optimum of less than 10 psu; the other two species are more broadly tolerant as juveniles. As they enter maturity, white and brown shrimp have very broad salinity optima; pink shrimp prefer salinities above 25 psu.

Commercial shrimpers in the St. Johns estuary and primarily in the nearshore Atlantic outside the mouth of the river harvest penaeid shrimp both for food and for recreational fishing bait. Commercial landings of white shrimp in the five-county northeast Florida area associated with the lower St. Johns River (Nassau, Duval, Clay, St. Johns, and Volusia) for the period 1986 through 2011 (Figure 6-24) shows shrimp landings in the general project area have increased relatively steadily over the past decade. Brown and pink shrimp landings have not been nearly so consistent (Figure 6-25). The Shrimp alliance estimated that northeast Florida landings between 2005 and 2008 were worth between \$1.97 and \$2.09 / lb of live shrimp, which would have a total market value of about \$6,000,000 to \$10,000,000 in those years. The majority (if not all) of the shrimp landings in the five-county area are assumed to come from populations supported by the St. Johns River estuary. (http://www.shrimpalliance.com/new/downloads/RequestforCertificationforNEFloridaasFiled.pdf)

Recreational fishing (primarily with a cast-net) for shrimp also has many practitioners in the LSJR during the late summer (Mattson et al., 2012). The landings from this recreational sector are not quantified in Florida, but surveys in other southeastern states suggests it could be substantial (Muncy, 1984).

FWC has estimated that the shrimp harvest is at or beyond the maximum sustainable and are suggesting that a larger minimum harvest size might help sustain or improve the value of the fishery (http://myfwc.com/media/195867/penaeid_shrimps.pdf). In the same article, the authors noted that the white shrimp harvests were most abundant in and adjacent to areas with extensive estuarine marshes. "White shrimp were landed mostly in Nassau, Duval, St. Johns, Brevard, and Dade counties on the Atlantic coast and Franklin County in the panhandle region of the Gulf in areas adjacent to extensive saltwater marshes and high freshwater run-off."

Effects of Predicted Changes in Salinity on Shrimp Species

Changes in salinity zones and salinity duration probabilities do not appear to have changed sufficiently in the mainstem LSJR to impact the penaeid shrimp populations. Assuming that salinities in the river main channel are relatively well reflected in the adjacent estuarine marshes near the mouth of the river and in Mill Cove, none of the proposed alternatives would appear to have significant impacts on blue crab or shrimp populations.

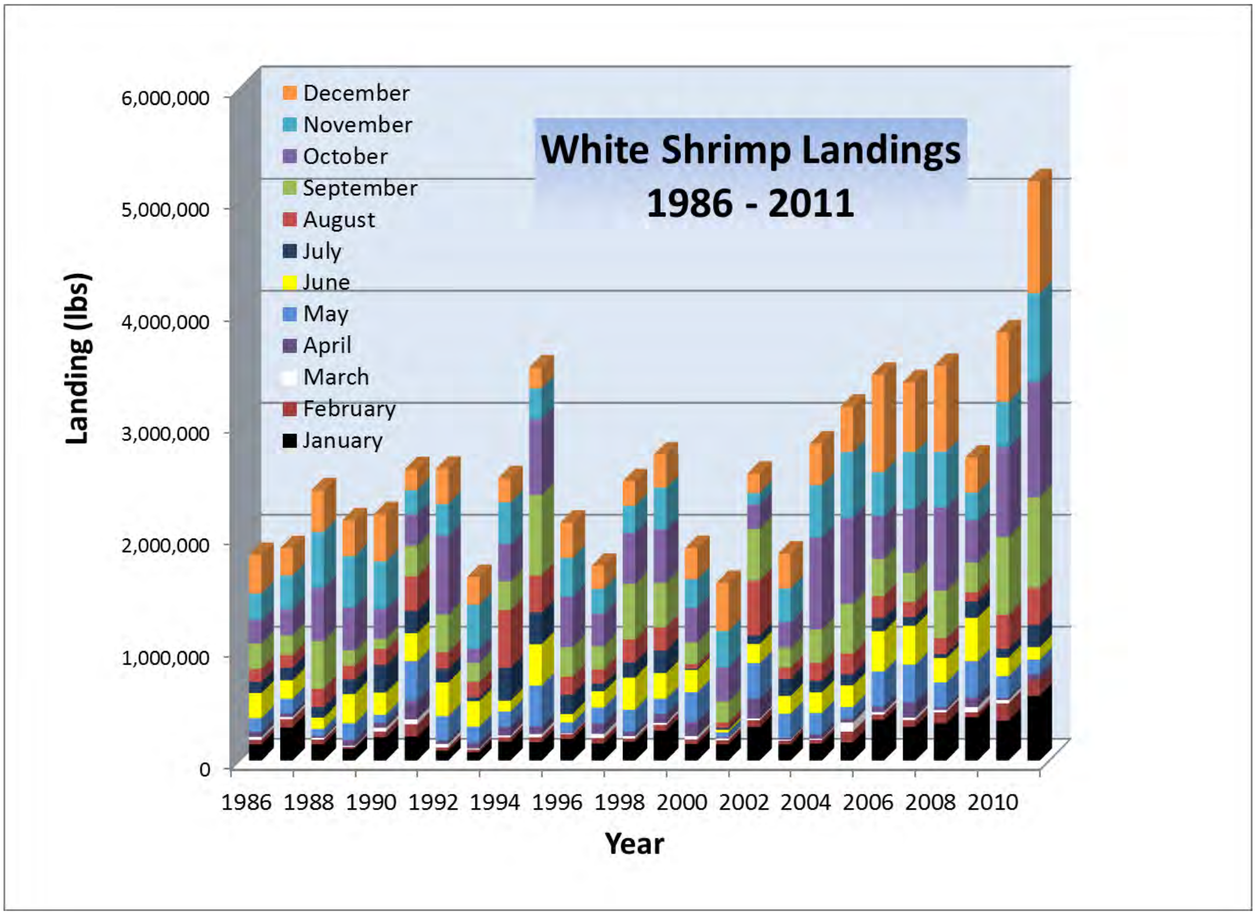

Figure 6.27 White Shrimp Landings Recorded by Florida Fish and Wildlife Conservation Commission. Monthly, 1986 – 2011

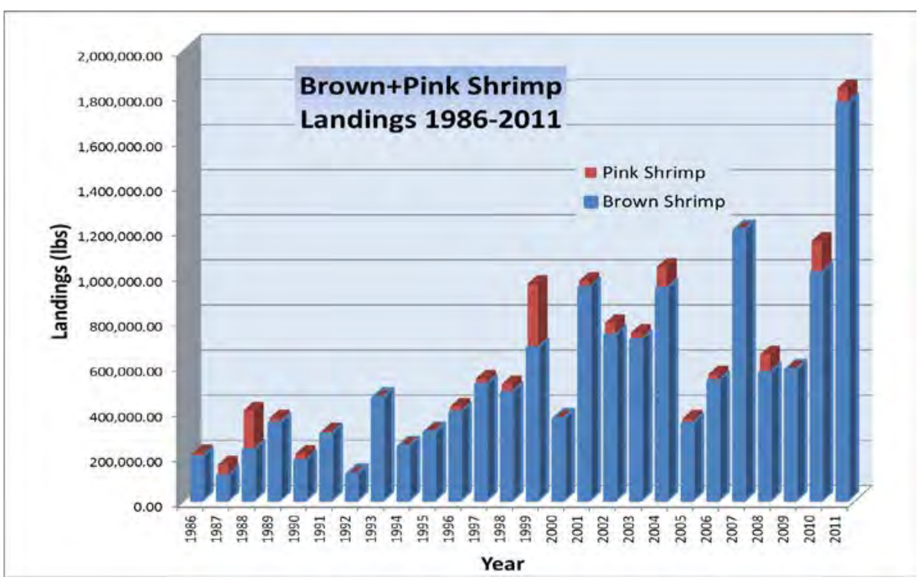

Figure 6.28 Brown and Pink Shrimp Landings Recorded by Florida Fish and Wildlife Conservation Commission. Monthly, 1986 – 2011

6.4.6 Potential Effects of Channel on Estuarine Benthic Communities

This chapter used the understanding of LSJR BMI communities developed in Mattson et al. (2012) and methods used to assess effects of water withdrawal on potential changes in BMI communities described in that same document, to assess changes in BMI communities due to a deepened Federal navigation channel in the first 13 miles of the LSJR. The methods applicable to this study suggested that only minor changes to the BMI community would occur, even for the deepest (50-ft) channel examined as an alternative in this report. The greatest changes in the river occur as a result of inter-annual variability in salinity. The effects identified by calculating salinity zones, both visually in the river and by comparing acreage, indicated that the shifts occurred as small upstream movements in the salinity boundaries. This becomes significant only when the changes affect SAV, which is an important habitat for BMI, although only in a small fraction of the river bottom cross section upstream of the Acosta Bridge. The conclusion reached by Mattson et al. regarding estuarine BMI community impacts from water withdrawal scenarios is equally applicable to channel deepening alternatives "because overall benthic community abundance was highest in the lowest salinity zones and because many of the benthic taxa and taxa groups examined by Montagna et al. (2011) exhibited peak abundance at or below 5 ppt, we maintain that loss of low salinity habitat (< 5 ppt) due to water withdrawals would be the principal concern for estuarine benthic communities."

Modeling indicated that the greatest changes in salinity occurred in the 0.5 ppt zone (the most upstream portion of the study area) as a result of inter-annual variation in salinity regimes. In dry years 1999 and 2000 the salinity increased above 0.5 ppt throughout the project study area (from just below Lake George to the river mouth). PDFA demonstrated that The greatest changes in salinity with the conditions created by different potential channel depths occurred upstream of Station SJR17, which occurs slightly upstream of the mouth of Mill Cove, for salinities around 18 ppt. Moving upriver, salinity affects ended at Station SR16, located near Shands Bridge, at the 0.5 ppt salinity level. Comparison of the most disparate conditions, current baseline and the 50-yr horizon alternatives, suggested the following:

- Inter-annual variability was a greater source of variability in terms of benthic salinity zones than were any of the alternatives.
- PDFA suggested that above about 18 ppt and downstream of Station SJR17, salinity dynamics were not greatly affected by the alternatives tested.
- Changes in salinity dynamics would most likely affect those BMIs in areas with background salinities less than 5 ppt, and within those areas, those with SAV.

- Location of salinity zones shifted only slightly upstream, regardless of alternative or time period considered.
- Percent habitat area losses of bottom habitat in the less than 0.5 ppt range generally distributed themselves over the salinity zones between 0.5 ppt and 18 ppt.
- The 18 -24 ppt salinity zone lost area in each comparison (baseline to 50-yr horizon 44-ft, 46-ft, and 50-ft salinity zones). This likely occurred because of the river morphology (narrow width and presence of a depth sill in that area, centered around the Tallyrand Terminal)
- Considering the comparison that should yield the greatest changes (baseline to 50-yr horizon alternatives) the ≥30 ppt salinity zone expanded the most compared to the other zones of the 50-yr horizon alternatives (>30 percent increase). All other percent changes, positive or negative, remained less than about 20%.
- The analyses performed did not suggest that project alternatives would impact commercially important invertebrates (blue crab and shrimp).

6.4.7 Uncertainties

The quantitative relationships between salinity and benthic communities and populations developed by Montagna et al. (2008, 2011) for the LSJR benthic communities and populations, provided a solid basis on which to interpret the salinity trends identified in the analyses described in this chapter. The biological trends in the river also fall well within the generally recognized influence of salinity gradients on benthic macroinvertebrates. The sources of uncertainty for the BMI community except for the commercially important species are the same as those recognized by Mattson et al. (2012) "Most sources of uncertainty are from limitations on the data collected from a segment (e.g., segment 1 [the downstream most end of the river] had relatively little existing data), or from the moderate levels of certainty associated with the predictive models. Overall, the levels of uncertainty associated with assessment of effects of benthic communities of the lower river and estuary are low to medium due to the development of moderately strong predictive models, strong supporting evidence from the literature, and good understanding of mechanisms".

No direct analysis of effect of salinity on shrimp or blue crabs was available, as the WSIS used inflow as the independent variable to assess changes in center of abundance for those species. Thus, the level of uncertainty with respect to the commercial species is high. Further, the EFDC model used to predict salinities functioned only within the mainstem; the model did not include the salinity dynamics of the tributaries or the estuarine marshes at the mouth of the river. While the mainstem salinity changes occurred upstream of the deepening area, potential changes in the tributaries upstream of the deepening project and in the marshes adjacent to the deepening project could not be assessed with the available models.

6.5 Recommendations

While most of the WSIS methods were implemented for this analysis, analysis of potential effects of salinity changes in the tributaries and marshes was not available with the EFDC model. In addition, the assessment of commercially important BMI species, implemented in the WSIS using freshwater inflows, was not applicable for assessment of salinity effects. Therefore, we recommend additional assessment of salinity changes to better understand potential effects of channel deepening on the BMI community. This work would necessarily include additional salinity modeling with a tool with a grid that included more of the tributary lengths and with programming to simulate marsh wetting and drying behaviors. Additional analysis of FIM data to examine salinity related behaviors of commercially important macroinvertebrates (if successful) combined with salinity modeling could provide useful insight into salinity effects on those populations.

7.0 PHYTOPLANKTON

The District's plankton working group for the WSIS evaluated potential effects of water withdrawal on plankton communities and dissolved oxygen. Coveney et al. (2012) describe the working group's plankton evaluation and development of the plankton empirical regression models and mechanistic models. This chapter reviews and summarizes the Coveney et al. (2012) empirical models and identifies the models' applicability for evaluation of effects of the Jacksonville Harbor deepening project. Chapter 8 discusses mechanistic model (EFDC/ICM-CEQUAL) development for evaluation of chlorophyll and dissolved oxygen.

Coveney et al. (2012) determined that the most important potential effects of water withdrawal on plankton communities relate to potential alteration of phytoplankton blooms. Algal blooms are common in the St. Johns River. Cyanobacteria dominate blooms in the freshwater part of the river; dinoflagellates in brackish parts. Potential adverse effects of algal blooms include increased dominance by toxic dinoflagellate species downstream and increased cyanobacterial bloom activity upstream, additional N loading from N_2-fixing cyanobacteria, altered phytoplankton community composition and increased amount of cyanobacterial toxins, dissolved oxygen depletion (with concomitant effects on fish populations), and changes in zooplankton community structure and reduction in fish production. The working group focused its attention on evaluation of these effects in River Segments 2 – 4, which encompass the lower freshwater and upper brackish water parts of the river.

The WSIS phytoplankton working group assessed the potential adverse effects of algal blooms with four bloom metrics and developed measurable variables associated with each metric. The four metrics and associated variables were:

1. Marine algal blooms as measured by maximum annual dinoflagellate biovolume
2. Change in N load as measured by annual mass of N added by N_2 fixation
3. Freshwater bloom magnitude as measured by maximum annual bloom chl-a and dissolved oxygen concentrations
4. Freshwater bloom duration as measured by duration of longest annual bloom.

7.1 WSIS Plankton Empirical Models

The plankton working group determined that the primary hydrologic variable governing algal bloom dynamics is water residence time. The group used the output from EFDC model simulations of river hydrology and phytoplankton characteristics from field collections to develop a series of empirical regression models allowing evaluation of the four algal metrics. The regression models tested 42 derived water age values as independent variables and the field measured phytoplankton bloom metrics as dependent variables. Field collections for phytoplankton data occurred at SJRWMD stations MP72, DTL, SRP, FP44, SJP, and PA32.

The EFDC model provided "water age" (i.e., residence time) data, defined as the "the average time that water resided in the model domain before reaching a specific site (model grid cell)". The model calculated water age in model cells at 30-second time intervals. Low water age values for the first three months of model simulations ("spin-up") precluded use of the results from that time period. The water age results for each cell corresponding to the phytoplankton data collection stations were processed to derive several different water age values as independent variables for the regression equations.

The working group derived water age variables for a series of five-quarter periods, each period beginning with the last quarter of a calendar year (quarter "A") and extending through the four quarters ("B", "C", "D", "E") of the following calendar year. Within each five-quarter period, the group derived minimum, maximum, and mean water age values for each of seven time periods (April - October, April – August, and quarters A, B, C, D, and E). The group also used the inverse of each derived variable as independent variables in the regression calculations.

The regression modeling resulted in a set of eight regression models addressing the four bloom metrics in River Segments 2 and 3 (Coveney et al., 2012). Six of the regression models are relevant to the river segments included in the Jacksonville Harbor deepening ecological modeling study area:

1. Dinoflagellate biovolume in Segment 2 (Regression A)
2. N_2-fixation in Segment 3 (Regression B)
3. Freshwater maximum Chl-a in Segment 2 (Regression C, applicable only in Doctors Lake; not in main stem)
4. Freshwater maximum Chl-a in Segment 3 (Regression D)
5. Freshwater bloom duration in Segment 2 (Regression F, applicable only in Doctors Lake; not in main stem)
6. Freshwater bloom duration in Segment 3 (Regression G)

Note that none of the WSIS phytoplankton models are applicable in River Segment 1.

The regression models require differing sets of water age input variables. Table 7.1 shows the variable set required for the six models.

Table 7.1 Input Variables For The Phytoplankton Empirical Regression Models (required variable indicated by "✓")

	Time Period						
Variable	**A**	**B**	**C**	**D**	**E**	**April - August**	**April - October**
Mean Water Age	✓			✓		✓	
Minimum Water Age				✓			
Maximum Water Age	✓		✓		✓		✓
Inverse Mean Water Age	✓	✓	✓		✓		✓
Inverse Minimum Water Age			✓	✓			✓
Inverse Maximum Water Age	✓				✓		

The methods applied by SJRWMD for assessment of phytoplankton are applicable in Segment 2 and Segment 3. The SJRWMD WSIS did not develop phytoplankton assessment methodology for Segment 1.

7.2 Application of the Phytoplankton Model for Jacksonville Harbor Deepening GRR-2 Ecological Effects Evaluation

The EFDC model outputs water age values for each layer of each model cell at one-hour time intervals. We post-processed the output data to produce vertically averaged daily water age values for the four cells corresponding to the SJRWMD phytoplankton sampling stations (Figure 7.1). From the daily water age values, we calculated the derived water age variables identified in Table 7.1. We set up spreadsheet models to apply the six applicable phytoplankton regressions described in Appendix 8.C of Coveney et al. (2012).

7.3 Results

The calculation of phytoplankton metrics with the regression equations produced some unexpected results. These results, some of which are illustrated in Figures 7.2 – 7.5, indicate that the regression models should not be used to evaluate the effects of Jacksonville Harbor deepening.

Figure 7.2 shows marine algal bloom (i.e., algal biomass) results from the Doctors Lake station in River Segment 2. The range of values generated from the regression equation appears reasonable in comparison to the distribution of values shown in the fit diagnostics for this equation in Coveney et al. (2012). Generally, annual variation in biomass appears greater than differences between the baseline and channel deepening alternatives.

Figure 7.3 shows nitrogen fixation for the Racy Point station in River Segment 3. The predicted data for 1998 appear unusually high and exceed observed and predicted values shown in the fit diagnostics. Again, the annual variation in predicted values exceeds the variation among the baseline and project alternatives.

Figure 7.4 shows results from the freshwater maximum chlorophyll-a regression at Racy Point in River Segment 3. As with the prior examples, annual variation exceeded variation among the simulated alternatives. Additionally, this model generated clearly unrealistic results with several of the simulations generating negative values for chlorophyll-a.

Figure 7.5 shows regression model results for freshwater bloom duration at Doctors Lake in River Segment 2. This model in some cases predicted algal blooms of negative duration, another unlikely occurrence in the river.

The results of the phytoplankton regression models are inconclusive regarding possible effects of Jacksonville Harbor deepening on phytoplankton communities. Some of the models produce apparently unreasonable results, which call into question the results from any of the regressions. Based on discussion and comments from SJRWMD staff, we believe that the regression models may function well only with data from the specific EFDC model used for the WSIS evaluation. The EFDC model modifications discussed in Chapter 2 and in Taylor (2012) may have resulted in minor variations in water age output values that were nonetheless sufficient to render the regression equations invalid for use with the Jacksonville Harbor Deepening GRR-2 ecological evaluation. This issue could perhaps be resolved through development of new regression equations based on the results of the Jacksonville Harbor Deepening GRR-2 EFDC model and the SJRWMD phytoplankton data set. However, such effort could require considerable time and with uncertainty of successful application.

7.4 Recommendations

Given these issues with application of the WSIS phytoplankton models, the best path for assessing potential harbor deepening impacts on phytoplankton communities lies with the CE-QUAL-ICM model under development and discussed separately in this report. The CE-QUAL-ICM model will include simulation of chlorophyll-a concentrations which will allow separate assessment of both magnitude and duration of phytoplankton blooms.

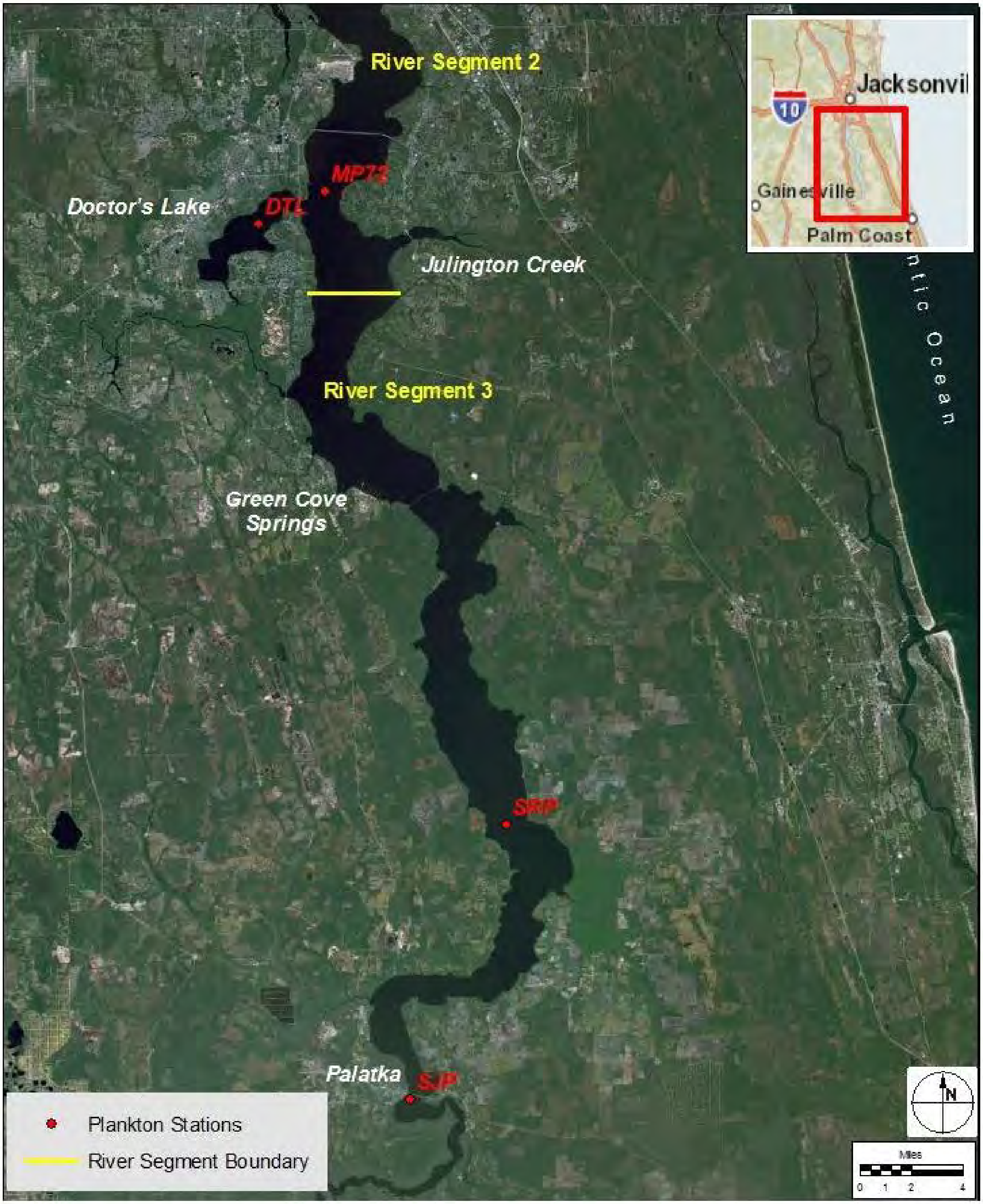

Figure 7.1 Phytoplankton Sampling Stations

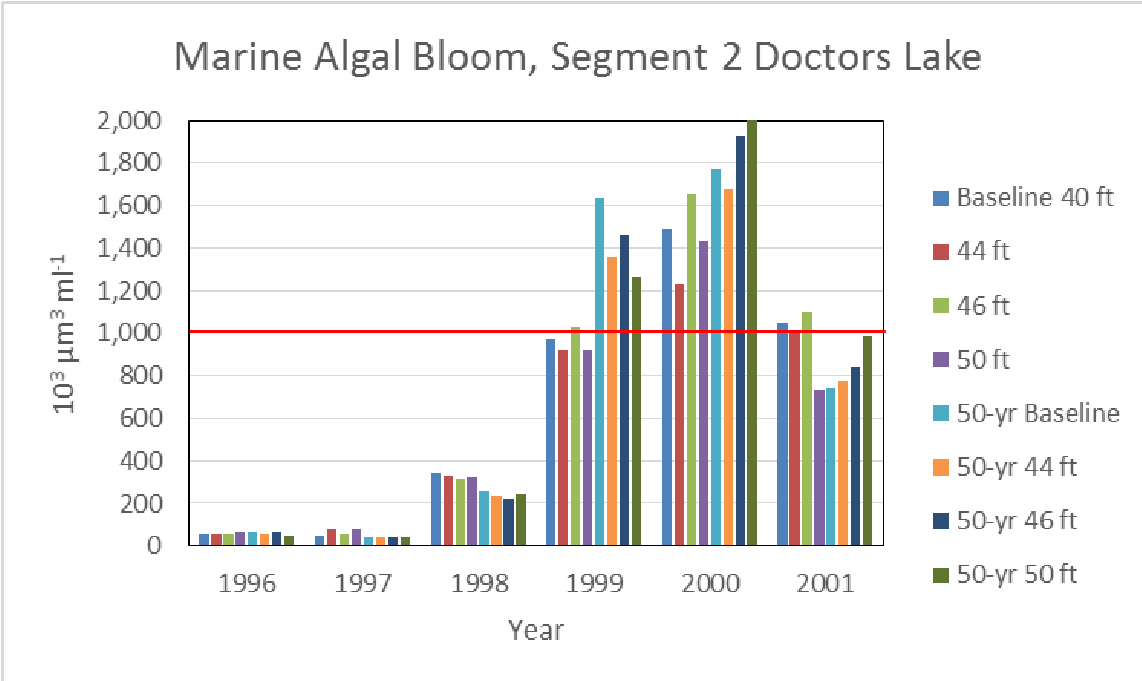

Figure 7.2 Regression Results — Marine Algal Bloom, Segment 2, Doctors Lake

Horizontal Red Line Indicates 1,000 X 103 µm3 ml-1 Effects Threshold

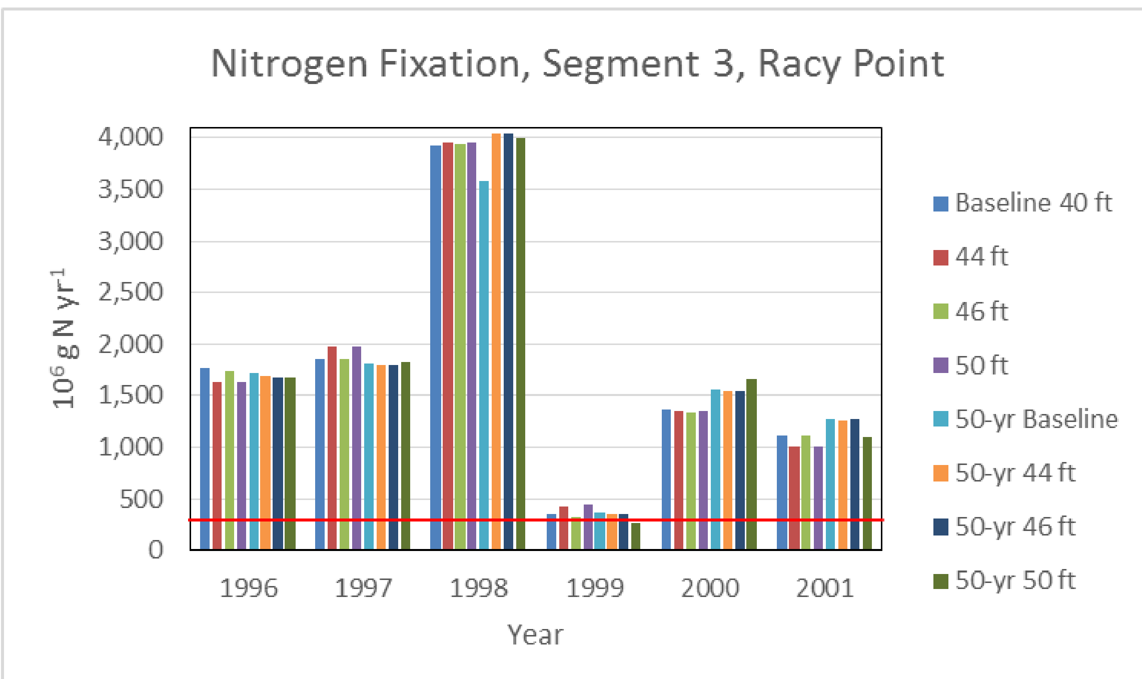

Figure 7.3 Regression Results — Nitrogen Fixation, Segment 3, Racy Point

Horizontal Red Line Indicates 308 X 10^6 G N Yr^{-1} Effects Threshold

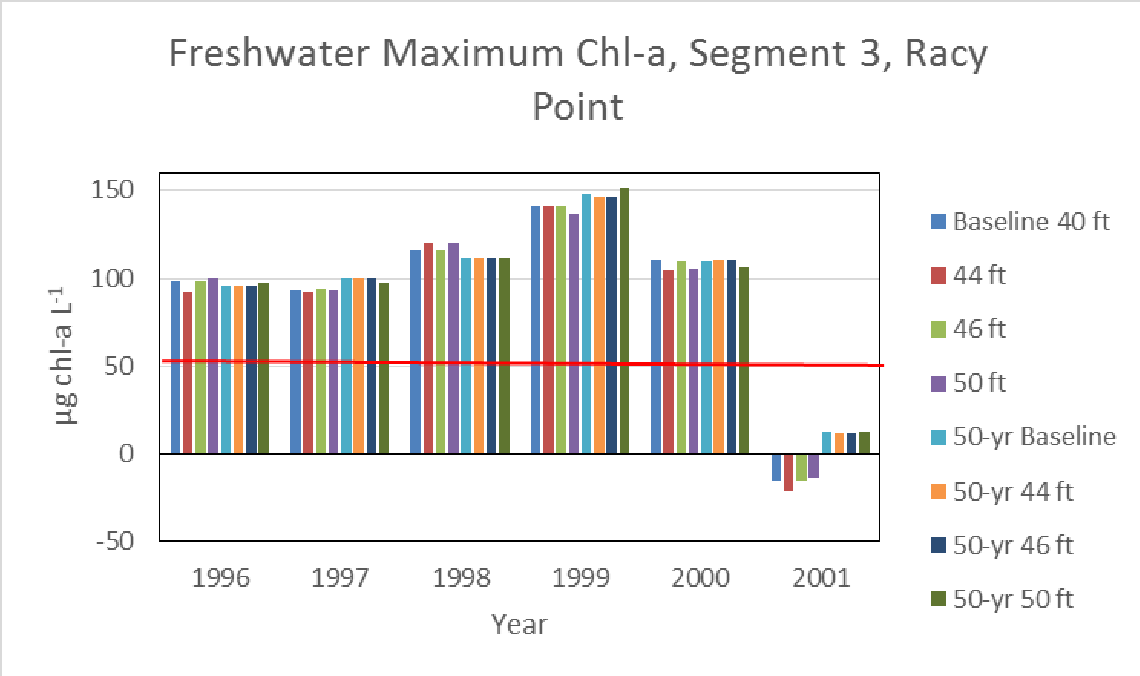

Figure 7.4 Regression Results — Freshwater Maximum Chl-A, Segment 3, Racy Point
Horizontal Red Line Indicates 50 µg Chl-A L^{-1} Effects Threshold

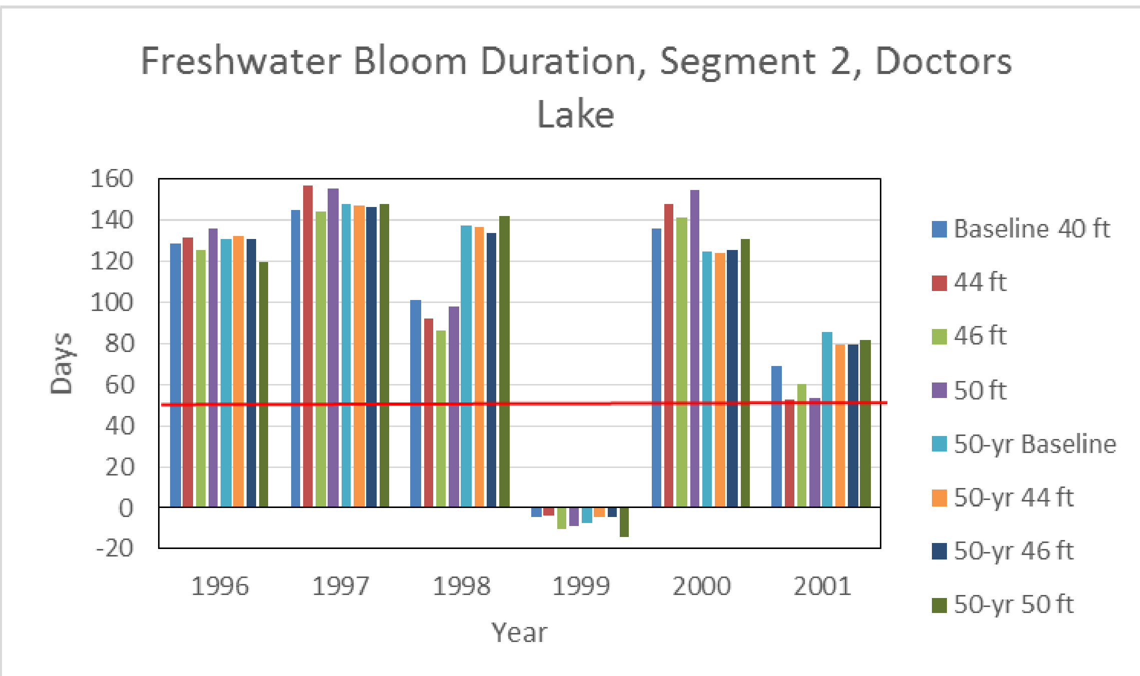

Figure 7.5 Regression Results — Freshwater Bloom Duration, Segment 2, Doctors Lake
Horizontal Red Line Indicates 50 Days Effects Threshold

8.0 WATER QUALITY

8.1 WSIS Water Quality Model

The District's phytoplankton working group for the WSIS evaluated potential effects of water withdrawal on chlorophyll a and dissolved oxygen with the CE-QUAL-ICM mechanistic model (Coveney et al. 2012). This chapter summarizes the Coveney et al. (2012) CE-QUAL-ICM modeling effort and identifies the models' applicability for evaluation of effects of the Jacksonville Harbor deepening project.

The WSIS study group used the CE-QUAL-ICM numerical water quality model to examine the effects of water withdrawal on chlorophyll a in River Segment 3. The WSIS CE-QUAL-ICM model was a modified version of a model originally developed by the SJRWMD for setting total maximum daily loads (TMDL) in the LSJR. The EFDC model provided hydrodynamic input for the CE-QUAL-ICM model. Coveney et al. (2012) describe the WSIS modifications to the original TMDL version of the model and the WSIS simulation conditions for the EFDC/CE-QUAL-ICM model system. Although the model tended to overpredict chlorophyll a concentrations relative to measured values, the WSIS group concluded that the EFDC/CE-QUAL-ICM model was useful for evaluation of chlorophyll concentration changes in response to hydrology changes.

8.2 Jacksonville Harbor Deepening GRR-2 Water Quality Model

For the Jacksonville Harbor Deepening GRR-2 ecological study, the USACE elected to apply the TMDL versions of the EFDC hydrodynamic and CE-QUAL-ICM water quality models. The objective in using the TMDL versions was to allow evaluation of both chlorophyll a and dissolved oxygen in the LSJR, a task for which the TMDL version appeared better suited because of its emphasis on simulating dissolved oxygen in River Segments 1, 2, and 3. Similar to the EFDC model mesh modifications described earlier, we modified the TMDL CE-QUAL-ICM model mesh to allow definition of river bathymetry following harbor deepening.

Appendix C describes development and application of the TMDL version of the EFDC hydrodynamic model to generate the hydrologic data for CE-QUAL-ICM. Appendix D describes calibration and verification of the TMDL version of the CE-QUAL-ICM model.

As described in Appendix D, we successfully calibrated and verified the TMDL version of the CE-QUAL-ICM model with the modified mesh and a pre-project bathymetry similar to that used by the SJRWMD. However, when we attempted simulations with the model bathymetry modified to reflect USACE baseline bathymetry and the dredged river channel, the CE-QUAL-ICM model suffered temporally and spatially localized instability issues which caused it to crash. We are currently working to identify the cause of the instability and develop recommendations to correct the problem.

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